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# ARMY AIRCRAFT SUBSYSTEM AND COMPONENT INSTALLATION DESIGN INVESTIGATION

Thomas N. Cook, et al

Kaman Aerospace Corporation

Prepared for:

Army Air Mobility Research and Development Laboratory

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# EUSTIS DIRECTORATE POSITION STATEMENT

This investigation is one of a series being conducted on Army helicopter maintenance procedures by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, with the objective of developing improved maintainability characteristics in future aircraft systems design.

This report addresses the problem of component design for installation/removal and presents conceptual design solutions thereto. These concepts will provide a basis for more detailed development in future Eustis Directorate programs.

Major Robert A. Mangum served as technical monitor for this contract.

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This report examines the design of major component installations in current-inventory helicopters and its effect on the man-hours required to replace these components. Recommendations are developed for improving the maintainability of future aircraft through state-of-the-art applications and new design concepts.

The study was accomplished in two phases. In the first, results of work accomplished under Contract DAAJ02-72-C-0065 were analyzed to

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identify design characteristics which contribute to the difficulty of removing and installing components. Seventeen generic types of components and six helicopter models were examined. Solutions to the problems were recommended which employ both state-of-the-art technology and advanced development concepts. Data gathered from manufacturers of helicopters and helicopter components was used to support this effort. Each design recommendation was evaluated to assess potential gains and penalties. Those in the advanced technology classification were ranked as candidates for further study.

In Phase II, twelve of the most promising advanced technology candidates were studied in greater depth and evaluated. Estimates were made of each concept's development cost, improvement potential and the probability that it could be brought to a successful production design.

# PREFACE

This investigation of aircraft subsystem and component installation design was performed under Contract DAAJ02-73-C-0082 for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The study was conducted under the technical direction of Major Robert A. Mangum of the Military Operations Technology Division.

The principal design investigative work was conducted by Mr. George W. Haire of the Kaman technical staff. Many other members of the Kaman staff contributed significantly to this program; the authors wish to acknowledge especially Messrs. J. Grant, R. Hartswick, B. Liff, J. Schauble, E. Sorant and C. Wirth.

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# INTRODUCTION

## BACKGROUND AND OBJECTIVES

Under Contract DAAJ02-72-C-0065,[1] a study was conducted to analyze the maintainability characteristics of major helicopter components. That study had several objectives. First, current-inventory Army helicopters were analyzed to identify the high man-hour tasks involved in maintaining major components of the aircraft. Each of the high man-hour tasks was then analyzed individually to establish the contribution of specific elements (fault isolation, access, buildup, etc.) to the overall task time. Factors considered significant to the performance time of individual tasks were documented. Finally, the knowledge acquired from the study was used to prepare a guide for use in maintainability analyses of future helicopter designs. As a result of this work, the aircraft components and maintenance functions contributing most to the high man-hour cost of operating today's helicopter fleet were identified. The overall problem was documented quantitatively in terms of the time required for maintenance and qualitatively in terms of the design factors which influence maintenance efficiency.

Some of the factors in current helicopter design found to have a significant bearing on component replacement time were accessibility, packaging and installation. Other contributors included complex plumbing and mechanical control systems, the number of detail parts involved in many installations, and the need to perform intricate alignments or adjustments as part of the component replacement task. Requirements for special skills and equipment were also found to complicate the maintenance process.

In the present study, the Army continued the original investigation into a problem-solving phase. Specifically, this investigation addressed the high maintenance effort expenditure created by the design for removal/installation of certain components. Design deficiencies uncovered via the previous work were analyzed with the goal of developing applications and concepts which will benefit future aircraft. Attention was directed toward problems which are common to several current model helicopters and which have a good probability of being carried over into the design of the next generation of

[1] Cook, T.N., Young, R.L., and Starses, F. E., MAINTAINABILITY ANALYSIS OF MAJOR HELICOPTER COMPONENTS, Kaman Aerospace Corporation; USAAMRDL Technical Report 73-43, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, August 1973, AD 769941.

helicopters. The study considered both state-of-the-art applications and the development of new engineering concepts in the solution of component installation design problems.

Nineteen generic helicopter components were specified by the Army for inclusion in the study:

1. Main Transmission
2. Main Transmission Input Quill
3. Forward Transmission
4. Aft Transmission
5. Engine Transmission
6. Combining Transmission
7. Intermediate Gearbox
8. Tail Rotor Gearbox
9. Engine-to-Transmission Drive Shaft
10. Tail Rotor Drive Shaft and Hangers
11. Engine
12. Engine Fuel Control
13. Main Rotor Blade
14. Main Rotor Hub
15. Tail Rotor Blade
16. Tail Rotor Hub
17. Swashplate Assembly
18. Hydraulic Flight Control Actuators
19. Starter Generator

Because the forward and aft transmissions of the tandem-rotor CH-47 helicopter are similar in both function and design to the main transmission in single main rotor helicopters, they were included with the main transmission for the purpose of this study, reducing the list to seventeen generic component groups.

Each of the seventeen generic component types was analyzed to determine deficiencies in the design for installation as applicable to the following current-inventory Army helicopters:

| | | |
|---|---|---|
| 1. | UH-1 | Utility |
| 2. | AH-1 | Attack |
| 3. | OH-6 | Observation |
| 4. | OH-58 | Observation |
| 5. | CH-47 | Cargo |
| 6. | CH-54 | Heavy Lift |

## TECHNICAL APPROACH

The first phase of this two-phase study began with review and analysis of the work accomplished under Contract DAAJ02-72-C-0065. Deficiencies in the design of hardware installations

which contribute significantly to the man-hours required to replace major components were identified. Recommendations for improving component installation designs then evolved from "round-table" type discussions with experienced helicopter designers representing the various engineering groups at Kaman and from a comprehensive gathering of state-of-the-art design data. Gathering state-of-the-art data included correspondence with numerous manufacturers of helicopter components and equipment.

The design recommendations thus generated were classified into two groups: (1) currently available or state-of-the-art solutions and (2) advanced technology design concepts. All of the recommendations in both groups were appraised by maintainability and design personnel to identify, to the extent permitted by the limited concept definitions, apparent benefits and penalties of an economic or technical nature. This appraisal included estimates of the potential savings in component replacement time and the probability of a successful solution being developed.

Phase II of the program, which comprised the major part of the contractual effort, was devoted to study of the twelve most promising concepts from the advanced technology group established in Phase I. The Phase II effort began with an exploratory period during which many possible design variations were considered for each of the twelve concepts. Maintainability and design engineers selected the design variations which appeared to offer the most improvement potential, and these were developed more fully. A sketch of each selected design is provided in this report. The final task of Phase II was an engineering critique which considered the effect of each design on maintenance, reliability, stress, aerodynamics, weight and cost. Required development costs and success probabilities were also estimated.

## ORGANIZATION OF THE REPORT

This report is divided into two major sections, one devoted to each phase of the study. Each section begins with a description of the methods of analysis employed in its respective study phase and then proceeds to document the results of the phase. Results of the Phase I effort are presented in seventeen subsections, one devoted to each of the generic components covered. The results of Phase II are presented in twelve subsections, one devoted to each of the advanced technology design studies conducted. Conclusions and recommendations are made at the end of the report.

# PHASE I GUIDELINES AND METHODS

## STATE-OF-THE-ART SURVEY

The work accomplished under Phase I of the program basically involved two major tasks: (1) the identification of design deficiencies related to component installations in helicopters and (2) the development and evaluation of design concept recommendations.

### Problem Definition

The process of selecting candidates for analysis involved thoughtful and careful evaluation of data from the study previously conducted under Contract DAAJ02-72-C-0065. It was recognized that deficiencies do not exist with all of the components covered by the prior analysis, at least to the extent that they would merit attention in the current study. Further, one component on a particular aircraft may present several problems deserving design study while that same component on another aircraft may present less serious concerns. Care was taken to prevent candidate selection on the basis of subjective considerations. The personnel performing this task were asked to develop lists of design deficiencies without regard to their opinion of the potential for improvement. This was done to avoid any tendency to exclude items on the basis of a subjective judgement of the chances for a workable solution.

The approach to the identification of design deficiencies used the maintenance task time data developed in the prior study as the baseline. The initial step was to establish the average replacement time for each of the nineteen generic component types to be covered by the study. These averages, which accounted for the number of components per aircraft and the estimated population of the six helicopter fleets, are shown in the following table. Next, maintenance task time data for each of the nineteen component types was assembled and correlated between helicopter models. The purpose of cross-correlating data in this manner was to identify which of the most time-consuming elements of the replacement task were common among two or more of the helicopter models represented.

After the major time-consuming elements of the replacement task for each of the nineteen component types were isolated, the next step was to determine what factors of design and support contributed to the maintenance time expenditures. Again, a concerted effort was made to seek out design deficiencies which were generally common and to avoid those that were very specific to a single model helicopter.

| MAN-HOURS TO REPLACE UNIT COMPONENT, FLEETWIDE WEIGHTED AVERAGES * | | |
|---|---|---|
| Rank | Component | Man-Hours |
| 1 | Aft Transmission | 42.6 |
| 2 | Engine | 42.4 |
| 3 | Forward Transmission | 39.0 |
| 4 | Main Transmission | 27.7 |
| 5 | Main Rotor Hub | 10.2 |
| 6 | Swashplate Assembly | 9.5 |
| 7 | Combining Transmission | 7.6 |
| 8 | Main Transmission Input Quill | 6.3 |
| 9 | Engine Fuel Control | 5.8 |
| 10 | Main Rotor Blade | 5.6 |
| 11 | Tail Rotor Gearbox | 5.3 |
| 12 | Engine Transmission | 4.5 |
| 13 | Tail Rotor Hub | 3.8 |
| 14 | Tail Rotor Blade | 3.8 |
| 15 | Hydraulic Flight Control Actuators | 3.6 |
| 16 | Intermediate Gearbox | 3.1 |
| 17 | Engine-to-Transmission Drive Shaft | 2.9 |
| 18 | Starter Generator | 2.7 |
| 19 | Tail Rotor Drive Shaft and Hangers | 2.2 |

*Based on aircraft model population and number of components per model.

## Development of Design Concept Recommendations

Developing concepts for improving the component installation design deficiencies uncovered in the preceding task was guided toward certain defined objectives. First, the concepts were

to be developed for incorporation in the design of future helicopters. They did not need to be applicable to current-inventory helicopters. Improvements in component reliability, vulnerability, durability, etc., were not being sought, although each of these had a recognized impact on maintenance. The objective was to make components easier to replace in the event of failure, not to make them fail less often.

A second guideline concerned the freedom for proposing innovative design solutions. While it was important that the concepts being proposed offered potential for real improvement and were technically feasible, it was equally important to avoid being biased by the practices and priorities of the past. It was acknowledged that maintenance had usually been ranked behind weight, cost and performance in the design of aircraft, a fact which may have been largely responsible for the problems being investigated. It was assumed that the Army would accept reasonable penalties in other areas in order to improve maintenance. Thus, promising ideas were not discounted on the basis of a preconceived notion that the weight or cost penalty would be unacceptable.

Another guideline defined the depth to which the design concepts would be developed. Each of the concepts would have to be explored and developed sufficiently to permit some gross assessment of the advantages and disadvantages and to obtain an estimate of the investment which would be required to fully develop the improvement. It was emphasized that designs were not required as a product of this study (only design concepts).

Within the guidelines just described, Kaman's principal design groups contributed recommendations related to the problem items in their areas of responsibility. This usually involved a "brainstorming" session in which maintainability, project and design people discussed the various problem items and suggested solutions for consideration. Frequently, designs of different helicopters, both those under study and other military and commercial types, were examined to determine whether certain characteristics tended to overcome or mitigate the problem under discussion. The ideas contributed by the design people ranged from very simple and substantially proven design principles to very sophisticated concepts, representing significant departures from present-day approaches to helicopter design.

## Assessment of Required Technology

Phase I of the program was defined in the Army's Work Statement as a "State-of-the-Art Survey". A principal requirement in this program phase, in addition to the problem definition task, was to assess the state of the art to determine those

deficiencies for which acceptable solutions are currently available.

An obvious question is raised by this requirement. How is the state of the art in maintainability defined? The state of the art in solid-state circuitry, for example, can be defined on the basis of currently applied technology and the status of on-going research and development in the field. Defining the state of the art in maintainability is much more difficult since maintainability is not a discipline pursued for its own sake. It is one of many characteristics which the designer must accommodate in a new product. The final product is rarely optimum with respect to any single factor such as manufacturing cost, weight, strength, or maintainability. It is hopefully the best combination of all factors, considering the relative priorities established.

Such was the difficulty presented by the need to assess the state of the art in maintainability. Had the ordering of priorities been different when today's helicopters were first designed, some of the problems in maintenance would surely not have occurred. The solution to the problems of maintainability becomes vastly more simple when maintainability is ranked first on the list of priorities. Although maintainability has received increased emphasis in succeeding generations of helicopters, it is highly unlikely that it will ever enjoy precedence over such goals as performance and cost. This fact has to be continually borne in mind when surveying the state of the art in maintainability. It is not merely what is possible but, more importantly, what is practical and acceptable. Care had to be taken to insure that undue concern for the practicality of ideas did not stifle imagination, however.

<u>Data Gathering</u>

State-of-the-art data gathering was pursued in two major areas. Seven U.S. distributors of commercial helicopters were contacted to solicit information pertinent to the design and maintenance of the aircraft they market. These included helicopters of both domestic and foreign manufacture whose design with respect to the installation of major components was thought to possibly offer a unique or innovative approach. The response to this survey was disappointing. Since Kaman competes directly or indirectly with other manufacturers of helicopters, several refused to supply data at any cost. Others asked an exhorbitant fee in view of the unknown value of the data to be supplied.

Requests for data were also sent to eighty manufacturers of aircraft components and equipment seeking information on new

concepts of installation, attachment, modularization, etc. While many companies did respond, few were able to supply any helpful information. As suspected at the outset of the survey, rarely does a component manufacturer become involved with the installation of his product in the aircraft, the kind of information needed for the study.

One further handicap to the state-of-the-art survey was the inability to secure design data on the Army's new generation of helicopters: UTTAS, AAH and HLH. The first two of these programs had been recently awarded at the time of the study, and both were in a highly competitive stage. The participating contractors in all three programs understandably regarded design data on their aircraft as extremely sensitive and unavailable to parties outside the Government.

The approach taken toward the state-of-the-art survey requirement, therefore, rather than seeking to determine what is available generally in the area of maintainability design, responded to specific design concept recommendations. A design proposal was considered to be within the state of the art if its implementation in a current or future helicopter could probably be effected without a major development effort. This definition extends "state of the art" beyond the category of off-the-shelf hardware and current design practice and allows for a low-cost, low-risk development in the process of application. Design concept proposals whose feasibility was presently uncertain or whose application would likely involve a substantial development effort were classified as "new concepts", i.e., beyond the state of the art.

Appraisal of Benefits and Penalties

It was expected that most of the concepts proposed to improve the installation of components in helicopters would incur penalties in aircraft weight, cost, size or performance. It was also recognized that improving one aspect of installation design might work to the detriment of another. It was important that these penalties be recognized and evaluated if feasible design solutions were to evolve from this work. By subjecting new concepts to all of the disciplines which are normally brought to bear on developing design, the penalties could be estimated, minimized and, when found excessive, become the basis for abandoning a concept.

The contributor of each design concept, assisted by a maintainability engineer, evaluated his proposal in terms of the expected benefits and penalties it represented. One consideration was the probable improvement or degradation in the installation of other helicopter components which would result

from applying the concept, i.e., the positive or negative secondary effects. Probable increases or reductions in performance, weight, cost and reliability were also considered. The impact of the concept on support resources (maintenance skills, tools, facilities, etc.) was evaluated.

Estimate of Expected Savings

Each design concept was evaluated to estimate the potential savings in component replacement time. Many concepts produced positive or negative secondary effects on other components of the helicopter, frequently not among those covered by the study. This, coupled with the sketchy definition of many concepts, did not permit a useful quantitative estimate of the man-hour savings. A maintainability engineer, after discussing the concept with the cognizant design specialist and considering all of the known ramifications of the concept, was asked to rate the anticipated man-hour savings as "low", "moderate", or "high". The estimate of savings then became a relative rather than an absolute indicator. After rating all of the design concepts in this manner, a review was made to verify that the estimates appeared reasonable in relation to other concepts of greater and/or lesser potential impact. These estimates were then used as one of the criteria for selecting concepts for Phase II.

Estimate of Success Probability

One requirement of the Phase II effort was to assess, for each of the design concepts studied, the probability of developing a successful solution. In order to decide which concepts to study in Phase II, however, it was necessary to estimate the probability that the idea or recommendation could be brought to the point of a viable concept. Some of the more venturesome design concepts advanced during Phase I promised large benefits in maintainability if they could be successfully brought to fruition, but they also presented major technical obstacles in design. Each contributor of a design concept proposal classified as a "new concept" was asked to assess the probability that a workable concept could be developed with a modest study effort in Phase II. He was not asked to predict the probability that the concept developed in Phase II could ultimately become a successful development, technically and economically, since there was usually insufficient knowledge available with which to make such a judgement.

For new concepts, therefore, the probability of success estimate (high, moderate, low) was the contributor's assessment of his ability to develop a viable concept in Phase II. Viability in these terms meant a concept with enough potential value to

be tested by the technical analysis which concluded Phase II. It was conceivable that the concept might be rejected at that point, however.

State-of-the-art concepts were those which the contributors believed could be applied to a present-day or future helicopter with little risk and within a modest development effort. Since these were not to be candidates for Phase II study, the contributor was asked to estimate the probability of successfully applying the design in an ultimate sense, i.e., to an actual aircraft today. In most cases there was little question of the technical feasibility of the design solution, since this was implicit in the state-of-the-art definition. Low success estimates usually reflected, therefore, other factors such as the weight, cost or performance degradation that implementation of the design would involve.

Ranking Concepts for Analysis in Phase II

To obtain the most efficient application of effort in Phase II, the problem areas which seemed most likely to yield to a modest design analysis with a high potential for positive results were to be pursued ahead of those where improvement appeared more questionable or the depth of analysis exceeded the scope of the program. This suggested the need for a program step during which problems were ranked according to improvement potential and the time required to develop a solution. As ideas were advanced for individual problem items, an estimate was made of the time needed to explore the idea along with an assessment of the probability that the idea would be acceptable and productive of real improvement.

An example of a problem which would be comparatively easy to analyze and for which a solution could be developed with little effort is that of maintaining close control of engine mount tolerances. The trade-off here is a higher initial manufacturing cost for a reduction in engine replacement time through elimination of shimming. Because the required study effort is small, a modest potential savings would be sufficient to warrant inclusion of the problem for study.

Toward the opposite end of the scale would be an analysis of concepts for overcoming the need to remove helicopter rotors during replacement of gearboxes. The investment in design time is substantial, and sufficient definition is needed to assess the impact of the concept on manufacturing cost, aircraft weight, stress, etc. A solution to the problem promises a large savings in future maintenance costs, but the investment in study time is comparably high. A more thorough judgement was needed before tasks of this complexity were studied. The

problem candidates were analyzed in this manner to determine an investment-to-benefit ratio for each candidate which was used to rank its relative merit for study. Candidates with the highest potential payoff for the investment in study time were then recommended for analysis ahead of those for which a smaller payoff was predicted. Maintainability engineering and design personnel jointly conducted the evaluation and problem ranking.

Four factors, all defined on a scale of high, low or moderate, were included in the concept ranking system. Two of these, the expected man-hour savings and the probability of success, were described earlier. A third factor considered in the ranking was that of the expected frequency. The anticipated man-hour savings is the per-unit improvement expected. The total value of the improvement, however, is a product of the per-unit savings and the frequency at which that savings will be realized. The frequency is, in turn, a product of the average number of applications per aircraft, the average reliability of the components to which the improvement applies, and the average component population (aircraft fleet).

The last factor used to rank candidates for Phase II was the expected study time. Again, a scale of high, low or moderate was used to express this factor. The study time estimate is related only to the concept development activity of Phase II and not to the time which would be required to develop the design concept completely. This latter estimate was developed for the selected design candidates at the conclusion of Phase II.

All of the new concept proposals developed during Phase I were subjected to the ranking process. A numerical value was assigned to each concept based on the average of the four ranking factors and the following weighting scheme:

| | Weight |
|---|---|
| Estimated Man-Hour Savings | |
| Low | 1 |
| Moderate | 2 |
| High | 3 |
| Estimated Frequency | |
| Low | 1 |
| Moderate | 2 |
| High | 3 |

| | Weight |
|---|---|
| **Estimated Success Probability** | |
| Low | 1 |
| Moderate | 2 |
| High | 3 |
| **Estimated Study Time** | |
| Low | 3 |
| Moderate | 2 |
| High | 1 |

The ranking process tended to assign the highest scores to those concepts which offered a large potential for improvement and a high probability of success for a low study effort. Lowest scores were assigned, conversely, to concepts which offered a small potential for improvement and a low probability of success for a large study effort.

The ranking scheme helped to show, in gross terms, those concepts which promised the greatest potential reward for the investment in Phase II study time. The results of this analysis were not, however, used as the sole criteria for establishing the Phase II work. The potential ramification of each concept in terms of weight, cost and performance was considered as well as the type of engineering expertise best suited to its development. (Some concepts might have been better explored by a component or equipment manufacturer, for example.)

Based on an overall assessment of the many factors involved, twelve design concepts were selected for study in Phase II.

## Documentation of Phase I Work

The results of the Phase I work are documented in seventeen individual sections, one devoted to each of the generic component types. Each section contains a brief summary of the component replacement time factors as derived from a review and evaluation of the forerunner to this study, entitled "Maintainability Analysis of Major Helicopter Components", Contract DAAJ02-72-C-0065. This is followed by a discussion of the design concept recommendations in the state-of-the-art category. Concepts of an advanced technology nature are presented at the conclusion of each section.

## MAIN TRANSMISSION

In addition to the main transmission in conventional helicopter designs with a single main rotor and tail rotor, this category includes the forward and aft transmission of the tandem-rotor, cargo class helicopter.

### REPLACEMENT TIME FACTORS

The bar chart of Figure 1 shows that the major contributors to replacement time for main transmissions are: removal and installation of other components and removal and installation of the transmission itself. Transferring of buildup items is a significant secondary contributor.

#### Removal of Other Components

Replacement of the main transmission requires removal and reinstallation of a number of other components. These are primarily components of the main rotor such as hub and blades but include also such items as the swashplate, main and tail rotor drive shafts, oil cooler blower, and hydraulic tank.

#### Handling

A substantial amount of main transmission replacement time on all helicopter models is devoted to erecting maintenance hoists, attaching slings, hoisting and maneuvering the transmission, and securing it to a transportation trailer or stand.

#### Transmission Attachment

Current methods of attaching transmissions to the airframe require the expenditure of an appreciable amount of time during replacement. This is especially true with the "soft-mounted" installations in several helicopter models. On one model, a special torque multiplier is required to install the transmission mount bolts which must be retorqued after a fixed number of flight-hours. The torque multiplier is time-consuming to set up and use.

#### Drive Shaft Alignment

In several models, the newly installed transmission must be leveled, after which alignment of the main drive shaft must be checked and adjusted. The drive shaft alignment procedures are complex and time-consuming.

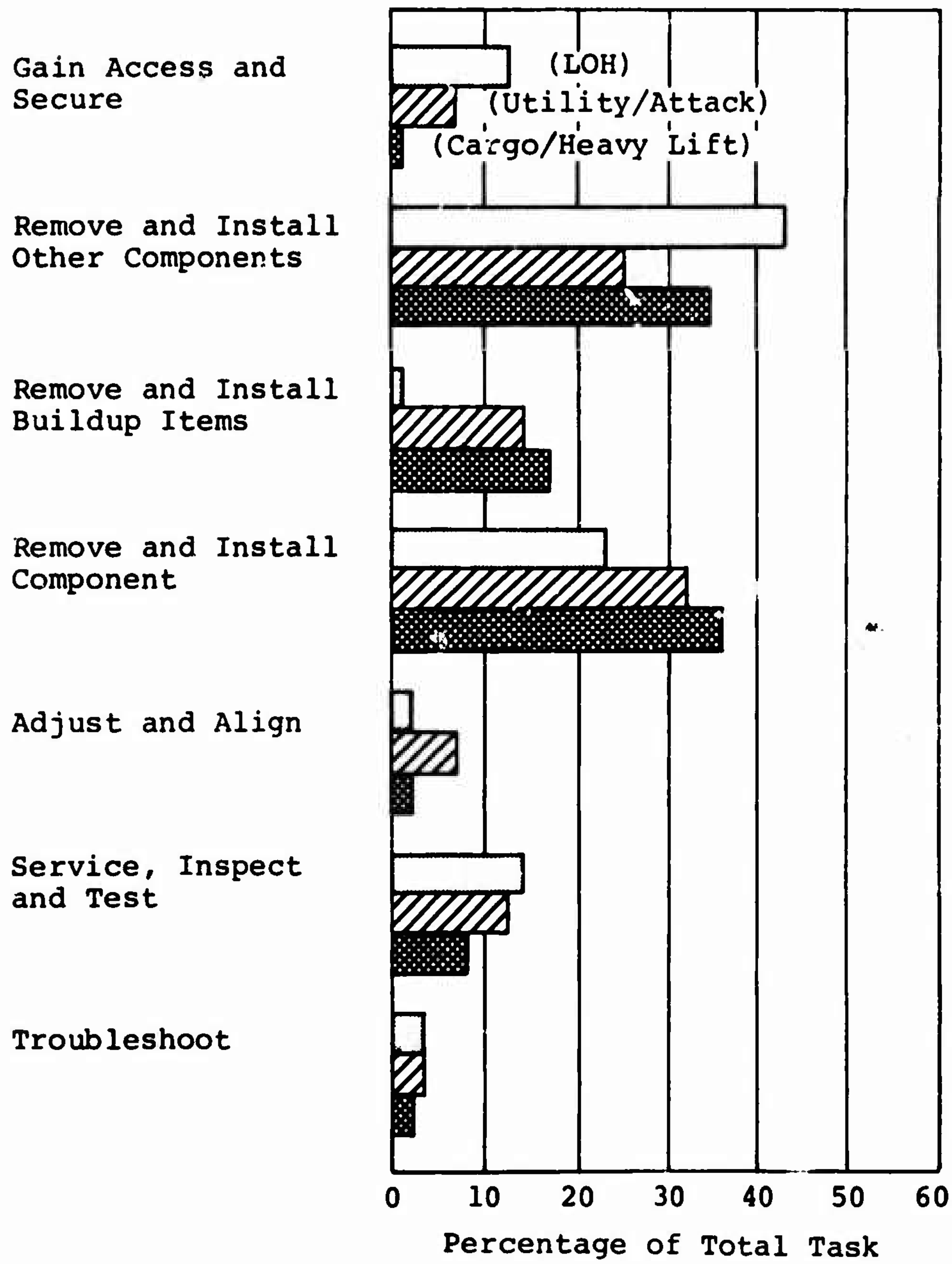


Figure 1. Component Replacement Time Distribution, Main Transmission.

## STATE-OF-THE-ART SOLUTIONS

### Remotely Mounted Fluid Reservoirs

The removal of fluid reservoirs such as the hydraulic tank, which is necessary to replace the main transmission in some helicopter models, might be avoided by installing such reservoirs on sliding transmission cowling. This would eliminate the need to remove the fluid reservoir when replacing the main transmission and reduce the potential for maintenance error and handling damage. The increased length of fluid lines would, however, add weight to the aircraft and reduce reliability (due to flexing, chafing, etc.). Tracks, rollers, latches, etc., for the sliding cowling would add additional weight. Extended lines when the cowling is open might become an obstacle for maintenance personnel. Sufficient clearance would have to be provided for the reservoir and the longer lines throughout the length of travel of the cowling. Lines would have to be carefully positioned to avoid fouling. The probability of developing a successful design is considered to be low.

### Integral Accessories

The time required to transfer accessories from one transmission to another could be lessened by making some of the accessories integral components of the transmission assembly. This would eliminate the time previously required to swap accessories and reduce the potential for incorrect installation and maintenance damage. A moderate man-hour savings would be realized. The weight and envelope of the transmission assembly and, consequently, the costs of transportation and storage would increase. The concept would also arbitrarily assign less than optimum replacement intervals for comparatively reliable accessories and increase the value of transmission assemblies in the supply pipeline. Location of accessories would have to be chosen to avoid the possibility of damage and assure adequate clearance when removing and installing the transmission. Packing crate modifications would be required. The probability of developing an acceptable design is high.

### Reduced Mount Point Redundancy

The time involved in detaching and attaching the transmission to its mount could be lessened by minimizing the redundancy in the number of transmission mount points. Fewer mount points would tend to reduce the time required to remove, install and

torque attaching bolts. Fewer attach points for a given transmission would require larger bolts with greater torque requirements. At some point, it becomes more troublesome to work with larger bolts than with more numerous smaller ones. This point is probably reached when high-capacity torque wrenches or torque multipliers must be employed. The optimum number of mount points would have to be established on the basis of local loads and replacement time considerations. The probability of developing an acceptable design is considered to be low.

Hard-Mounting Transmissions

Several helicopter models employ soft-mounted transmissions which involve greater installation complexity than hard-mounted designs. Hard mounting would reduce the number of tasks and the time involved in the replacement process. This type of installation eliminates the need to disassemble and inspect details of the soft-mount assembly. It also eliminates dampers and all maintenance associated with them. Alignment of main and tail rotor drive shafts would remain more constant, resulting in better reliability. A weight savings would accrue. Simplifying the mounts would decrease the possibility of incorrect assembly. Rigidly mounted transmissions permit use of rigid tubing for oil, hydraulics, etc., in lieu of heavier flex hoses. A moderate man-hour savings could be anticipated.

Hard mounting tends to produce higher vibration and noise levels, however. Some means of vibration and noise reduction would have to be included in the hard-mount design. Redundancy in mount complexity must be traded off against greater accuracy in alignment. Developing an acceptable hard-mount design for those models currently using soft mounts is estimated to have a moderate probability of success.

Piloted Bolts for Barrel Nuts

Applications where barrel nuts are used at transmission mount points might be improved through the use of a bolt which will pilot into the nut before thread engagement. This would simplify bolt engagement and reduce the incidents of cross-threading. A small man-hour savings would result. Piloted bolts would be heavier and more costly, however, and would have to be specially designed to align and engage loosely restrained nuts without cross-threading. Developing a successful design has a high probability.

## Improved Barrel Nut Restraint

In applications where barrel nuts are used at transmission mount points, the nut might be restrained to provide better alignment. This would simplify bolt engagement and reduce the incidents of cross-threading. A small man-hour savings would result. The design would likely be heavier and more costly, however, and the restraint would have to be capable of holding the nuts in acceptable alignment to ease the task of properly engaging the retaining bolts. Developing an acceptable design has a moderate probability of success.

## Barrel Nut Elimination

The difficulty experienced with barrel nut applications at transmission mount points might be overcome by replacing the barrel nut with a press-fit steel bar, drilled and tapped. Maintenance time would be reduced by eliminating the barrel nut alignment task. Manufacturing cost and weight would increase, however, and replacement of cross-threaded or worn nuts would become a machining task. Drilling and tapping would have to be precise to minimize the chance of cross-threading, and consideration would have to be given to a means of replacing worn nuts. Probability of a successful design is high.

## Increased Mounting Bolt Torque

In those installations which call for rechecking mount bolt torque after some period of operation, an increase in the initial torque value on the bolts might eliminate this requirement. This would allow some loss of pinch on the stackup due to surface seating or fretting without losing the minimum torque requirement. It would also eliminate the need to check torque after some period of operation, resulting in a moderate man-hour savings. It may, however, require the use of higher strength bolts which are larger and heavier. The higher torque bolts would have to maintain the minimum torque requirement, with acceptable consistency, after some loss of pinch on the stackup. The probability of achieving this in design is considered to be moderate.

## Controlled Mount Bolt Squareness

In those installations which call for rechecking mount bolt torque after some period of operation, better control of the squareness of the mount bolt heads and nuts during manufacture might eliminate this requirement. This would distribute bolt load over a greater bearing area, thereby reducing pinch loss

due to seating or fretting. Minimum torque values would be more easily maintained on mount bolts, eliminating the need to check torque after a period of operation and producing a moderate man-hour savings. An increase in initial manufacturing cost will likely be incurred, however. The bolt head and nut contact areas would have to be sufficient to maintain the minimum torque requirement. Some increase in clearance at the mount points may be needed. Success probability is considered to be moderate.

Larger Mount Bolt Washers

In those installations which require rechecking mount bolt torque after a period of operation, an increase in the size of the washers under the moun_ nuts to improve seating might eliminate the post-operation torque check. The bolt load would be distributed over a greater bearing area, thereby reducing the pinch loss due to seating or fretting. Minimum torque values would be more easily maintained, eliminating the need to retorque the mount bolts and producing a moderate man-hour savings. There would be a slight increase in weight and cost, however. The washer would have to provide sufficient bearing area to maintain the minimum torque requirement. Some increase in clearance at the mount points may be needed. Success probability is considered to be moderate.

Larger Mount Bolts With Spacers

In those installations which call for rechecking transmission mount bolt torque after some period of operation, the use of longer bolts with spacers to mount the transmission might eliminate the post-operation torque check. Stretch of increased bolt length would compensate for loss of pinch on stackup as surfaces seat or fret. Minimum torque values would be maintained, eliminating the need to check torque after a period of operation and producing a moderate man-hour savings. The installation would be complicated slightly, however, and a small weight penalty would be suffered. The length of the mounting bolts would have to be sufficient to overcome loss of pinch with increased stretch and maintain the minimum torque requirement during aircraft operation. The consistency of this capability would have to be verified. Success probability is considered to be moderate.

Increased Number of Mount Bolts

The use of a special torque multiplier to install the transmission mount bolts in some installations might be avoided by increasing the number of mount bolts while reducing bolt size

and torque. This would permit the use of readily available torque wrenches and result in a moderate man-hour savings. Increased machining costs for the transmission and airframe mount fittings would be incurred, however. The optimum number of mount points would have to be established on the basis of local loads and replacement time considerations. The accessibility of mount points will influence the number that can be accommodated. Success probability is considered to be high.

Integral Drive Shaft Coupling

In one installation, the drive shaft flexible coupling must be separated from the drive shaft and transmission and installed on the replacement transmission. The time required to transfer the coupling could be eliminated by making the coupling a component of the transmission. This ould eliminate the need to transfer the coupling to the replacement transmission, resulting in a small man-hour savings. The potential for improper installation of the coupling on the transmission would also be eliminated. It would, however, increase the value of transmissions in the supply pipeline and subject the coupling to handling damage during packaging and at the depot. Careful consideration would have to be given to the location and attachment of couplings to avoid limiting access to other parts of the transmission. Coupling parts should be made interchangeable. A special packing crate design would be required. The probability of developing an acceptable design is considered to be high.

Integral Plumbing Connections

On some transmissions, plumbing connections such as elbows, reducers and unions must be swapped from the old to new transmissions. The time involved in this task could be eliminated by making these items details of the transmission assembly. This eliminates the need to transfer plumbing parts from one transmission to another and achieves a moderate man-hour savings. It would also reduce the opportunity for stripped threads in castings which are costly to repair. The shipping weight and pipeline cost of the transmission would increase slightly, however. The location and method of attaching these parts would have to be selected to avoid restricting access to other parts of the transmission. Probability of developing a successful design is high.

Related State-of-the-Art Solutions

A number of state-of-the art solutions having a potentially beneficial effect on the installation of helicopter main transmissions are described elsewhere in this report. These pertain

to components of the helicopter which have installation design problems in common with the main transmission, which are physically or functionally connected to the transmission, or which, because of their proximity to the transmission, tend to restrict or obstruct its installation. These solutions and the generic components under which they are found are listed below:

| Concept | Reference |
|---|---|
| Close-Tolerance Engine Mount Pads | Engine |
| Common Junction Points for Lines and Wires | Engine |
| "V" Band Attachment of Accessories | Engine |
| Accurately Located Shaft Attachment Points | Tail Rotor Drive Shaft and Hangers |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing main transmission replacement time in helicopters were those considered beyond the present state of the art as defined for this program. These concepts, described below, became candidates for the design study phase.

### Mounting Bolts in Shear

In those installations which require a special torque multiplier to install the transmission mount bolts, the installation might be modified to place the bolts in shear instead of tension. Relatively low torque values would be needed on the bolts, eliminating the need for a torque multiplier and effecting a small man-hour savings. Tolerances on the location of the mounts would have to be held closely, especially if more than three mounts are used. Greater space in proximity to the mount would be needed to allow for extraction of the bolt. A bolt extractor may be required. There will be a weight penalty. Consideration would have to be given to a means of extracting the bolts to provide the necessary ac ɔss. The probability of developing an acceptable design is considered to be moderate.

Integral Lube System

The time involved in disconnecting and swapping external lube lines could be eliminated if the main transmission were a wet sump design with integral lines, coolers, filters, etc. A moderate man-hour savings would be realized. The weight of the transmission would increase but the overall effect on the helicopter would probably be a net weight reduction. The oil cooler blower could be mounted on a boss of the transmission and driven directly without resorting to a shaft with flexible couplings. The integral lube system should be more reliable and less vulnerable to combat damage. The aircraft would be less cluttered in the area of the transmission, tending to ease other maintenance tasks.

Shipping and overhaul costs for the heavier, bulkier and more complex transmission would increase, however. Malfunctioning lube system components would cause the entire transmission to be replaced. Major changes in the transmission would require considerable design and development time. Keeping the overall transmission envelope within reasonable dimensions may be difficult. The probability of developing a successful design is considered to be moderate.

Modularized Transmission

Replacement time might be reduced significantly by modularizing the main transmission with provisions for supporting the main rotor shaft, hub and rotor blades such that they need not be removed to replace the transmission. This concept was selected as one of the twelve design study projects.

Transmission Replacement Through Cabin

The need to remove components of the main rotor might be eliminated by mounting the main transmission so that it is removed by lowering it into the aircraft cabin, leaving the entire main rotor supported independently. This would eliminate the need to disturb the main rotor or its controls to replace the transmission. A crane, hoist or other means of lifting the transmission from the helicopter would be unnecessary. A moderate to large man-hour savings could be realized depending on the design. The transmission might be lowered manually in light aircraft but would probably require external support equipment for utility and heavier class helicopters. The opening in the cabin roof, even if covered with panels, could allow leaked oil and hydraulic fluid to enter the cabin area. Access to the transmission would require removal of the cabin sound insulation and roof panel. Aircraft weight and cost might in-

crease substantially due to the provisions for lowering and conveying the transmission to and from its installed position.

The main rotor mast would need to be independent of the transmission and self-supporting. Provisions would be needed to lower and raise the transmission into place and to convey it laterally to and from the aircraft exterior, either suspended or along the cabin floor. The removal procedure would probably impose limitations on the transmission envelope and mounting scheme. The probability of developing a cost-effective design is considered to be low.

Transmission Located in Lower Fuselage

Another approach to avoid having to remove the main rotor for transmission replacement would be to relocate the main transmission to the bottom of the fuselage where it could be detached from an independently supported rotor mast and slid on rails out one side of the fuselage and onto a transportation trailer. The main transmission could be replaced without disturbing the main rotor or its controls. A crane, hoist or other means of lifting the transmission would be unnecessary. A moderate to large man-hour savings could be realized depending upon the design. A self-supporting rotor shaft would have to be introduced between the transmission and rotor hub, however. The shaft would add weight and probably diminish overall drive train reliability. Cabin space would be sacrificed and aircraft weight and cost might increase substantially.

Relocation of the transmission would require considerable design and development time. Dissipation of transmission heat may be difficult. If the engine and tail rotor gearboxes are not relocated as well, drive shafting would have to be routed indirectly or at an angle. Removal procedures might impose limitations on the overall transmission size envelope. The probability of developing a successful design is considered to be low.

Quick-Disconnect Mount Fittings

Replacement time might be reduced by developing quick-disconnect mount fittings for the main transmission. The quick disconnect would have to provide the proper torque for mounting as well as positive locking provisions and would likely involve weight and cost penalties, however. The probability of developing a successful design is considered to be low.

DAVI Mounting System

Use of the dynamic antiresonant vibration isolation (DAVI)

system for mounting the transmission is a possible approach to eliminating the maintenance associated with the rubber mounts in some installations. The DAVI does not rely on rubber as the energy-absorbing medium and thus eliminates such maintenance problems as spring rate changes due to aging, deterioration or delamination caused by exposure to lube oil, etc. The system would reduce helicopter vibration levels, resulting in longer service lives for many components. The man-hour savings as related to transmission replacement alone will be low, however.

There will be a space penalty and a possible weight penalty with the installation. The application of DAVI mounts would require considerable design time. Adequate space and proper clearance are required for the function of the DAVI units. Design success probability is considered to be moderate to high, depending upon the helicopter configuration.

## Telescoping Drive Shafts

The need to remove the engine-to-transmission drive shaft and the tail rotor drive shaft in order to replace the main transmission could be avoided by designing the shafts to telescope out of the way after having been disconnected from the transmission. The moderate man-hour savings that this feature would produce tends to be offset by several disadvantages. A way of supporting the disconnected shaft would have to be devised so that the attached coupling is not overstressed. The collapsed shaft would be subject to maintenance damage during a transmission change. The telescoping mechanism might require lubrication and would tend to degrade the reliability of the shaft. Design problems would include establishing the proper location for the locking mechanism and maintaining balance control. The probability of developing an acceptable design is considered to be low.

## Related Design Concepts

Design concept solutions having a potentially beneficial effect on the main transmission are described elsewhere in this report. These pertain to components of the helicopter which have installation design problems in common with the main transmission, which are physically or functionally connected to the transmission, or which, because of their proximity to the transmission, tend to restrict or obstruct its installation. These concepts and the generic components under which they are

found are listed below:

| Concept | Reference |
| --- | --- |
| Quick Attach/Detach for Accessories | Engine |
| Flange-Mounted Engine | Engine |
| Built-In Shaft Alignment Indicator | Engine |
| Increased Misalignment Coupling | Engine |
| Electronic Tachometer Pickup | Engine |
| Quick-Disconnect Drive Shaft | Tail Rotor Drive Shaft and Hangers |

## MAIN TRANSMISSION INPUT QUILL

### REPLACEMENT TIME FACTORS

The bar chart of Figure 2 shows that the major contributors to replacement time for the main transmission input quill are removal and installation of other components and removal and installation of the quill itself.

#### Removal of Other Components

Replacement of the input quill assembly or input seal requires removal and reinstallation of the engine-to-transmission drive shaft and the dust separator if installed. In the case of one aircraft, the engine must be disconnected and moved forward to obtain access to the quill.

#### Jack Screws and Heat Application

In one series of aircraft, the input quills are removed from the transmission housing using jack screws. Because of the tight fit, installation of the replacement quill may require the application of heat to the transmission housing.

#### Removal of Cowling, Fairing, Etc.

Access to the input quill may require removal and reinstallation of one or more of the following items: transmission fairing, engine intake fairing, top section of the engine intake baffle, a section of the intake screen and the transmission cowling.

#### Mating of Bearing Inner Race With Rollers

During installation of the quill in one series of aircraft, a rubber plug is temporarily positioned in the roller input bearing to hold the rollers against the outer race. The plug must be inserted in the bearing from the inside of the transmission through a mounting port on the side of the transmission.

### STATE-OF-THE-ART SOLUTIONS

#### Looser Fit Input Quill

The use of jack screws and heat to remove and install tight-fitting input quills in some aircraft might be alleviated by designing a quill installation with a looser fit. A moderate man-hour savings could be realized during quill replacement, and the potential for damaging the quill upon removal or installation would be reduced. The gear mesh will not be as

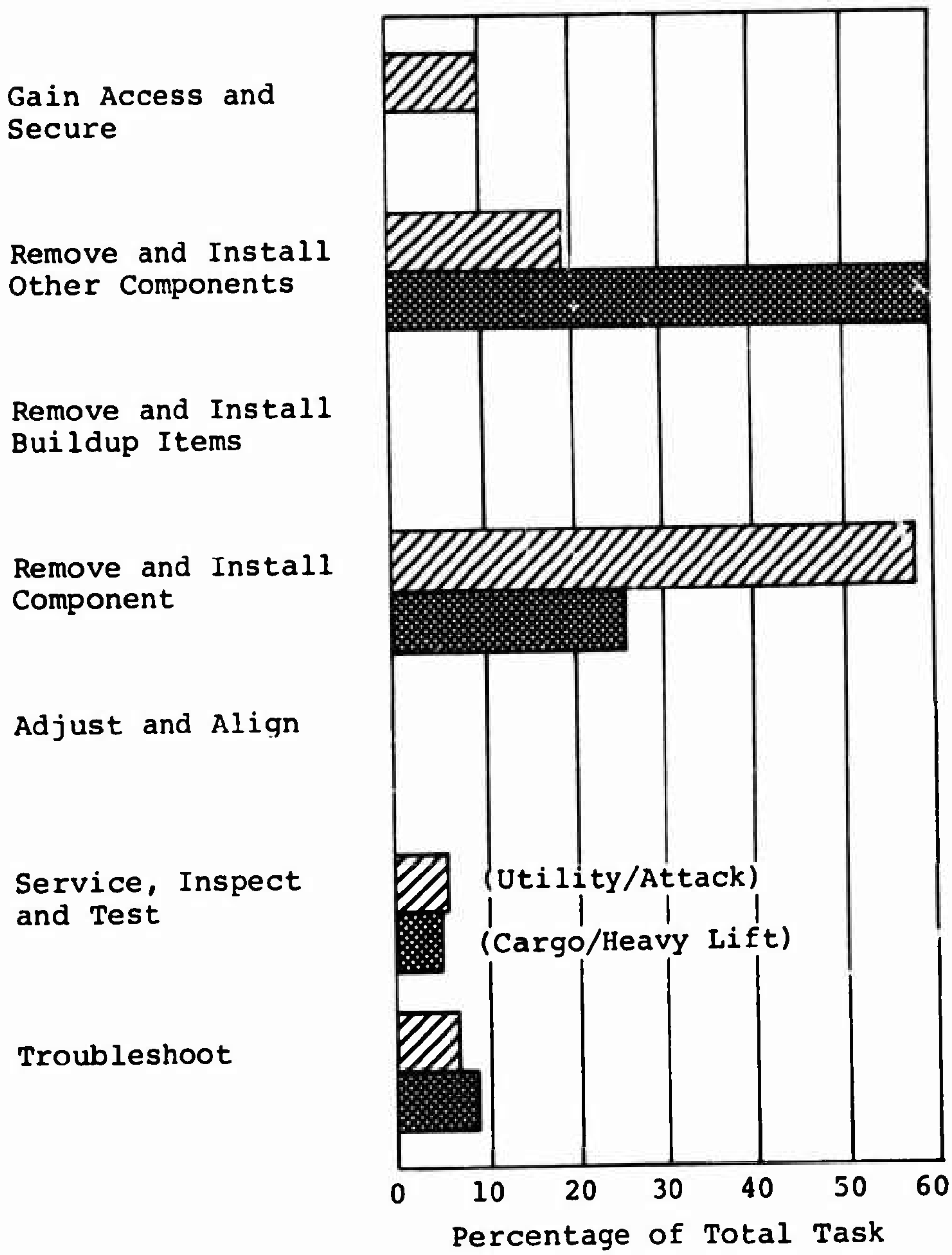


Figure 2. Component Replacement Time Distribution, Main Transmission Input Quill.

closely controlled and reliability may be degraded, however. Design problems would include developing adequate wear resistance through material hardness and/or proper lubrication. Gear mesh requirements will limit the amount of looseness which can be tolerated. The probability of developing an acceptable design is considered to be low.

Separately Replaceable Input Seals

Seal leaks are a major cause of quill replacements. The design of a seal which can be changed without replacing the quill could substantially reduce the frequency of quill replacement. In addition to the man-hour savings inherent in separately replaceable seals, a logistics benefit would accrue from the need to stock fewer replacement quills. Materials and configuration would have to be chosen so that the incidence of seal leaks is not unacceptably increased. The probability of developing a successful design is considered to be high.

Leads on Bearing Rollers

The difficulty of engaging the input quill upon installation might be overcome by adding leads to the bearing rollers to facilitate alignment. This would eliminate the need to hold the rollers against the bearing outer race with a plug when installing the quill and would reduce replacement man-hours. The reduced bearing capacity must be compensated by increased bearing size and weight. The probability of developing an acceptable design is considered to be moderate.

Related State-of-the-Art Solutions

A number of state-of-the-art solutions having a potentially beneficial effect on the installation of helicopter main transmission input quills are described elsewhere in this report. These pertain to other components of the helicopter which have installation design problems in common with the input quill or which, because of their proximity, tend to obstruct the quill installation. These solutions and the generic components under which they are found are listed below:

| Concept | Reference |
|---|---|
| Hinged Air Particle Separator | Engine-to-Transmission Drive Shaft |
| Elimination of Nonfunctional Cowling | Engine |
| Quick-Release Cowling and Fairing | Engine |

| Concept | Reference |
| --- | --- |
| Sliding Engine Cowls | Engine |
| Hinged and Hydraulically Operated Cowling | Engine |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing main transmission input quill replacement time in helicopters was one considered to be beyond the present state of the art as defined for this program. This concept, described below, became a candidate for the design study phase.

### Split-Cones Quill Installation

The need to use jack screws and heat to remove and install input quills in some aircraft might be eliminated through adaptation of a split-cones design similar to that used in the design of propeller shafts. The gear mesh would not be as closely controlled as the current tight-fitting sleeve with flange, however, and reliability would likely be degraded. The possibility of mismatching cone halves would also occur. An important consideration is the ability to develop a design which will preclude cone seizing, although a special puller may be required to extract the cone halves. A weight penalty will be suffered. The probability of developing an acceptable design is considered to be low.

### Related Design Concepts

Three design concept solutions having a potentially beneficial effect on the main transmission input quill are described elsewhere in this report. These pertain to other components which must be removed for access to the input quill. These concepts and the generic components under which they are found are listed below:

| Concept | Reference |
| --- | --- |
| Flange-Mounted Engine | Engine |
| Cowling and Fairing Assembled as a Removable Unit | Engine |
| Telescoping Drive Shafts | Main Transmission |

## ENGINE TRANSMISSION

The engine transmission is found only on the tandem-rotor, twin-engine cargo class helicopter.

### REPLACEMENT TIME FACTORS

The bar chart of Figure 3 shows that the major contributors to replacement time for the engine transmission are those tasks associated with replacement of the transmission itself.

#### Removal of Drive Shaft

Replacement of engine transmission requires that the engine-transmission-to-combining-transmission drive shaft be disconnected and reconnected. This is the single most time-consuming task involved in replacement of the transmission.

#### Alignment of Barrel Nuts

Difficulty is sometimes encountered when attempting to align the barrel nuts into which the engine transmission fairing retaining bolts thread. Cross-threading occasionally occurs.

#### Swapping Lube Lines

Two lube lines are first disconnected from fittings at the engine drive shaft fairing, and then swapped from the old to the new transmission.

### STATE-OF-THE-ART SOLUTIONS

#### Studs for Cowling Attachment

The difficulty experienced in the alignment of barrel nuts retaining the cowling to the engine transmission might be alleviated through the use of studs in place of the barrel nuts. This would eliminate the need to align individual barrel nuts but would require precise, simultaneous alignment of the cowling with its mounting studs. The probability of developing a time-saving design is considered to be low.

#### Wet-Sump Transmission

The time involved in disconnecting and swapping lube lines during a transmission change could be eliminated by making such transmissions wet-sump lubricated. The wet-sump would be of value only if the oil cooler could be made integral with the

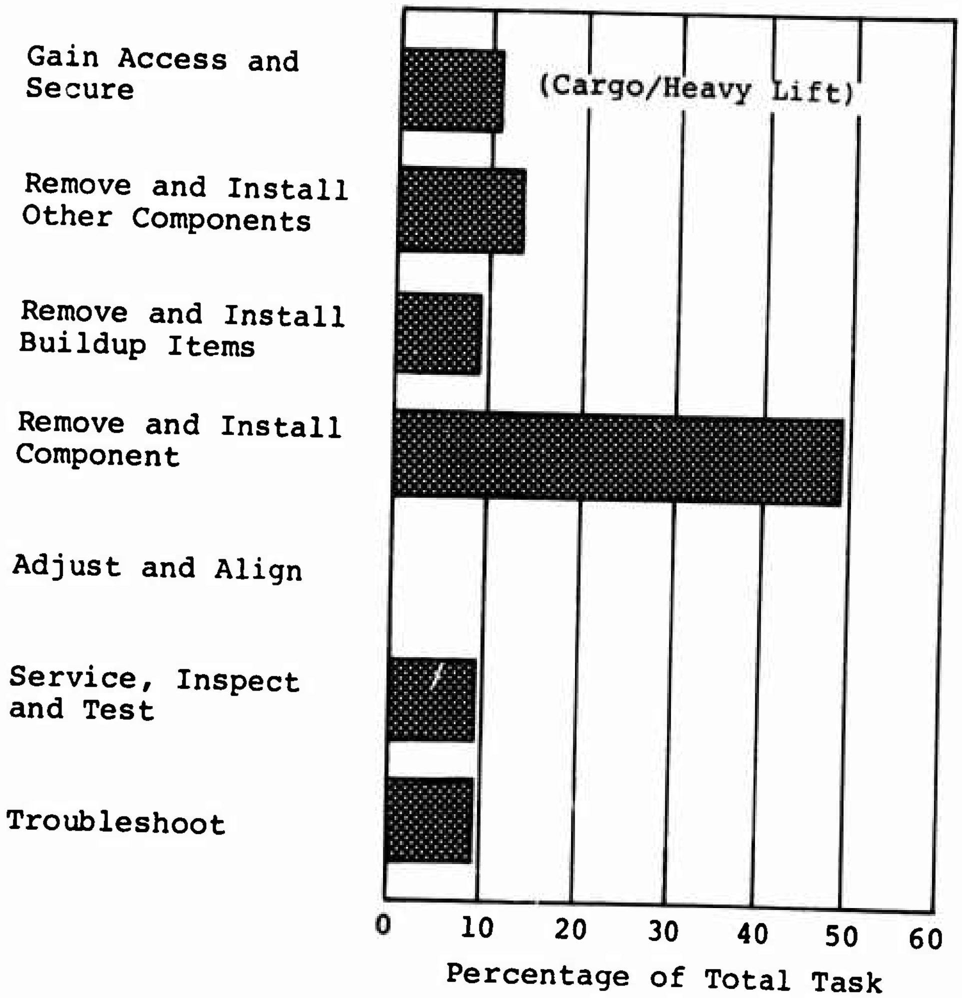


Figure 3. Component Replacement Time Distribution, Engine Transmission.

transmission. Otherwise, the oil lines would not be eliminated. Making the cooler integral with the transmission may not be feasible, however, because the transmission is located in the engine air inlet stream, where such a configuration might increase inlet air temperature unacceptably. Another disadvantage arises from the need to increase the gearbox envelope to accommodate the wet-sump design and the small maintenance savings it would effect. Pursuit of the concept could only be justified on the basis of secondary technical and economic benefits. The probability of developing a technically functional design is considered to be moderate, however.

Integral Lube Lines and Fittings

The time involved in disconnecting and swapping lube lines and fittings during a transmission change could be lessened by making the lines and fittings integral parts of the transmission assembly. This would eliminate the need to transfer these items to the replacement transmission. It would not eliminate the disconnection of one end of each line from the airframe portion of the lube system, however. Leaving fittings installed would reduce the chances of stripped threads in castings which are costly to repair. Leaving lines and fittings attached would make them more vulnerable to maintenance damage during handling of the transmission, however. Making lines and fittings integral with the transmission will add to the cost of spare units in the supply pipeline, complicate packaging and add to shipping weight slightly. Careful design consideration would have to be given to the routing of lube lines and the placement of support attachments and fittings to avoid interference with other areas of the transmission requiring access for maintenance. The design concept appears to be technically feasible if it can be justified economically.

Related State-of-the-Art Solutions

A number of state-of-the-art solutions having a potentially beneficial effect on the installation of engine transmissions are described elsewhere in this report. These pertain to components of the helicopter which have installation design problems in common with the engine transmission. These solutions and the generic component under which they are found are as follows:

| Concept | Reference |
|---|---|
| Piloted Bolts for Barrel Nuts | Main Transmission |
| Improved Barrel Nut Restraint | Main Transmission |

| Concept | Reference |
|---|---|
| Barrel Nut Elimination | Main Transmission |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing engine transmission replacement time in helicopters was one considered to be beyond the present state of the art as defined for this program. This concept, described below, became a candidate for the design study phase.

### Transmission Lubrication Via Engine Oil System

The time involved in disconnecting components of the engine transmission oil system could be eliminated if the transmission were lubricated via the engine oil system. This would eliminate the separate oil pump, cooler and blower and the external lube lines presently used. A relatively small man-hour savings would be realized at replacement of the transmission, but maintenance benefits would also accrue from the elimination of components, reduction in leakage rates, etc. This concept would involve substantial trade-offs and considerable study of such factors as oil volume, pump capacity, cooling rates, etc. The probability of developing a technically acceptable and cost-effective design is considered to be moderate.

### Related Design Concepts

Several design concept solutions having a potentially beneficial effect on the engine transmission are described elsewhere in this report. These pertain to components of the helicopter which have installation design problems in common with the engine transmission. These concepts and the generic components under which they are found are listed below:

| Concept | Reference |
|---|---|
| Quick-Disconnect Drive Shaft | Tail Rotor Drive Shaft and Hangers |
| Overcenter Coupling Clamp Latch | Tail Rotor Drive Shaft and Hangers |
| Telescoping Drive Shafts | Main Transmission |

## COMBINING TRANSMISSION

The combining transmission is used only in the tandem-rotor, twin-engine cargo class helicopter.

## REPLACEMENT TIME FACTORS

The bar chart of Figure 4 shows that the major contributors to replacement time for the combining transmission are removal and installation of other components, removal and installation of buildup items, and removal and installation of the transmission itself.

### Removal of Drive Shafts

Replacement of the combining transmission requires removal and reinstallation of both engine shafts which input to the transmission, and disconnection and reconnection of the two synchronizing shafts which output from the transmission.

### Transfer of Buildup Items

Items which must be transferred from old to new transmission include both engine shaft adapter and plate assemblies (couplings) and numerous elbows, reducers, unions, etc.

### Erection of Maintenance Hoist

A significant amount of time is devoted to erecting the maintenance hoist, attaching a sling, hoisting and maneuvering the transmission, and securing it to a transportation trailer or stand.

### Disconnection of Wires and Lines

Replacement of the transmission requires disconnection and reconnection of many electrical wires and plumbing lines. These include wires for three temperature transmitters, chip detector, phasing switch, and lube lines to oil screens, filters and relief valves.

## STATE-OF-THE-ART SOLUTIONS

### Related State-of-the-Art Solutions

A number of state-of-the-art solutions having potential benefit to replacement of the combining transmission have been developed for other components of the helicopter which have

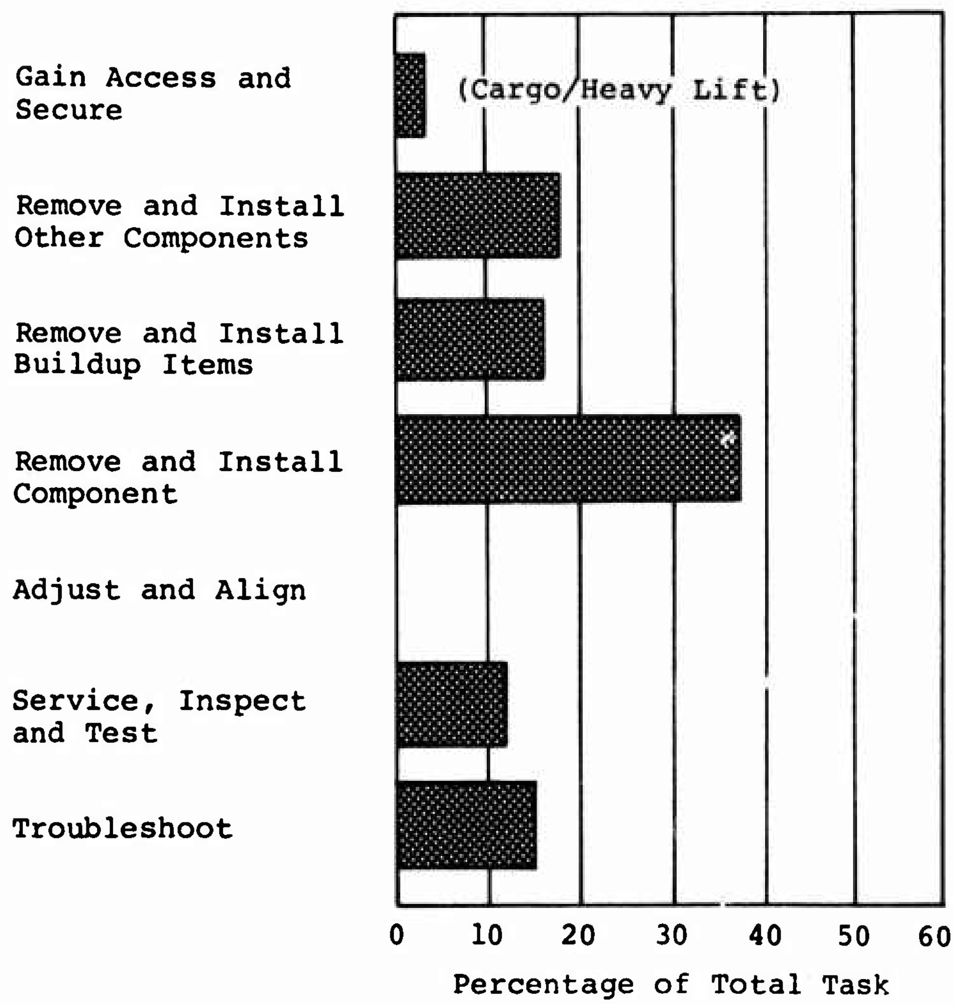


Figure 4. Component Replacement Time Distribution, Combining Transmission.

installation design problems in common with the combining transmission. These concepts and the generic components under which they are listed below:

| Concept | Reference |
|---|---|
| Common Junction Points for Lines and Wires | Engine |
| Multiwire Single Electrical Connector | Engine |
| Manifold Connectors | Engine |
| Integral Drive Shaft Couplings | Main Transmission |
| Integral Lube Lines and Fittings | Engine Transmission |
| Wet-Sump Transmission | Engine Transmission |

## DESIGN CONCEPT CANDIDATES

One design concept candidate proposed for main transmission installations may have application to the maintenance involved with removal and installation of external lube lines to the combining transmission:

| Concept | Reference |
|---|---|
| Integral Lube System | Main Transmission |

## INTERMEDIATE GEARBOX

### REPLACEMENT TIME FACTORS

The bar chart of Figure 5 shows that the major contributors to replacement time for intermediate gearboxes are removal and installation of other components, removal and installation of the gearbox itself, and post-installation servicing.

#### Removal of Tail Rotor Shafts

The single most common maintenance time-consumer in the replacement of intermediate gearboxes is the need to disconnect, and possibly remove from the aircraft, the tail rotor drive shafts on the input and output sides of the gearbox.

### DESIGN CONCEPT CANDIDATES

The installation design concepts proposed in this study which will benefit replacement of the intermediate gearbox are those which facilitate detachment and attachment of the input and output tail rotor drive shafts. These concepts and the generic components under which they are found are:

| Concept | Reference |
| --- | --- |
| Quick-Disconnect Drive Shaft | Tail Rotor Drive Shaft and Hangers |
| Overcenter Coupling Clamp Latch | Tail Rotor Drive Shaft and Hangers |
| Telescoping Drive Shafts | Main Transmission |

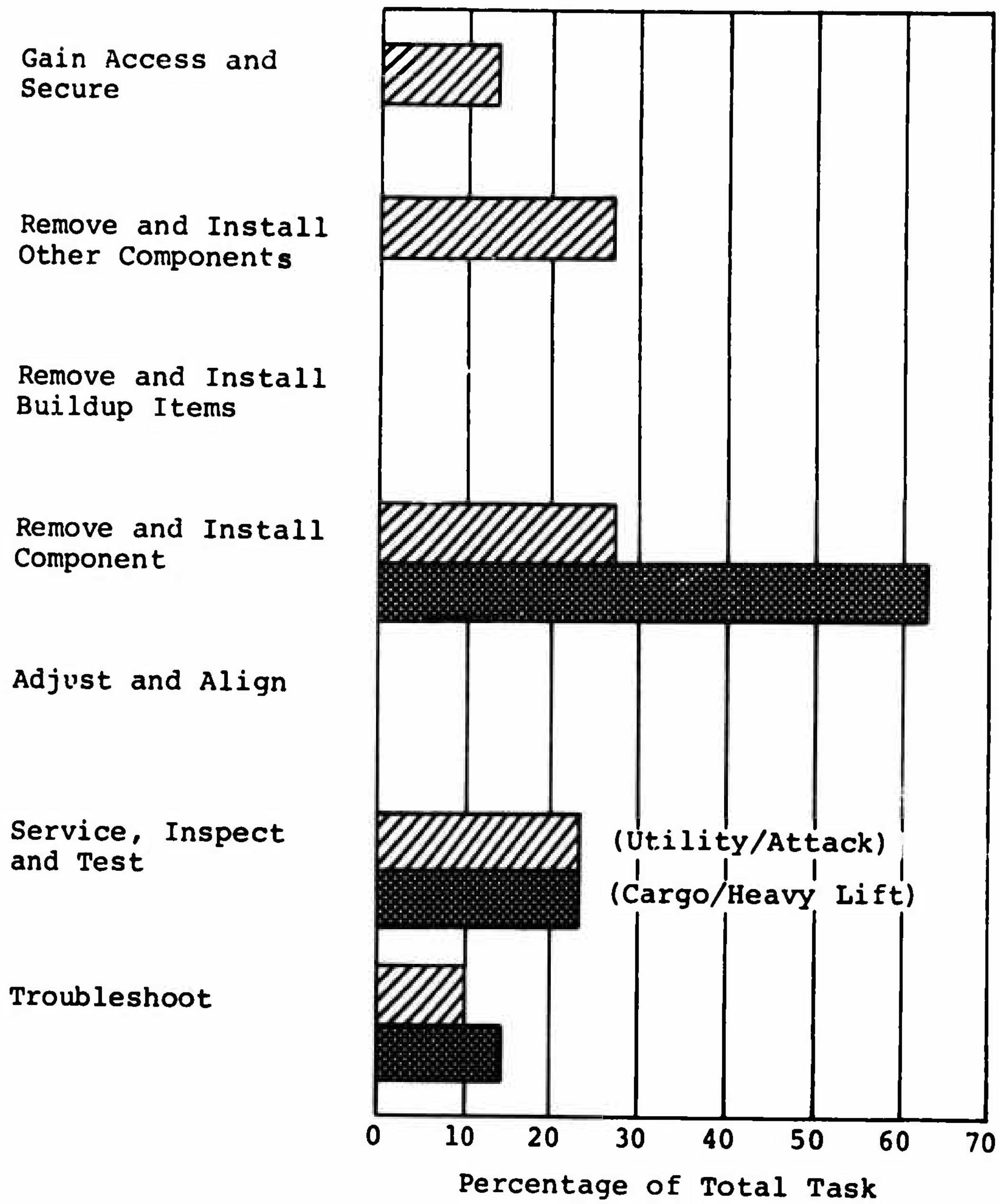


Figure 5. Component Replacement Time Distribution, Intermediate Gearbox.

# TAIL ROTOR GEARBOX

## REPLACEMENT TIME FACTORS

The bar chart of Figure 6 shows that the major contributors to replacement time for the tail rotor gearbox are removal and installation of other components and removal and installation of the gearbox itself.

### Removal of Other Components

The single most common time-consumer in the replacement of tail rotor gearboxes is the need to remove and reinstall the tail rotor drive shaft, flight control linkages and tail rotor assembly.

## STATE-OF-THE-ART SOLUTIONS

### Related State-of-the-Art Solutions

One state-of-the-art solution has been proposed which reduces the time required to reinstall the tail rotor drive shaft after replacement of a gearbox. This concept and the generic component under which it is found are listed below:

| Concept | Reference |
|---|---|
| Accurately Located Shaft Attachment Points | Tail Rotor Drive Shaft and Hangers |

## DESIGN CONCEPT CANDIDATES

One concept has been proposed for reducing tail rotor gearbox replacement time in helicopters which is considered beyond the state of the art as defined for this program. This concept, described below, became a candidate for the design study phase.

### Modularized Tail Rotor Gearbox

A significant amount of time expended on replacement of tail rotor gearboxes is devoted to removing and reinstalling the tail rotor assembly and tail rotor controls and to performing post-installation rigging and tracking adjustments. Most of this time could be eliminated if the gearbox were modularized to allow the tail rotor assembly and controls to remain in place and undisturbed during replacement of the gearbox. This concept is one of the twelve design study projects described

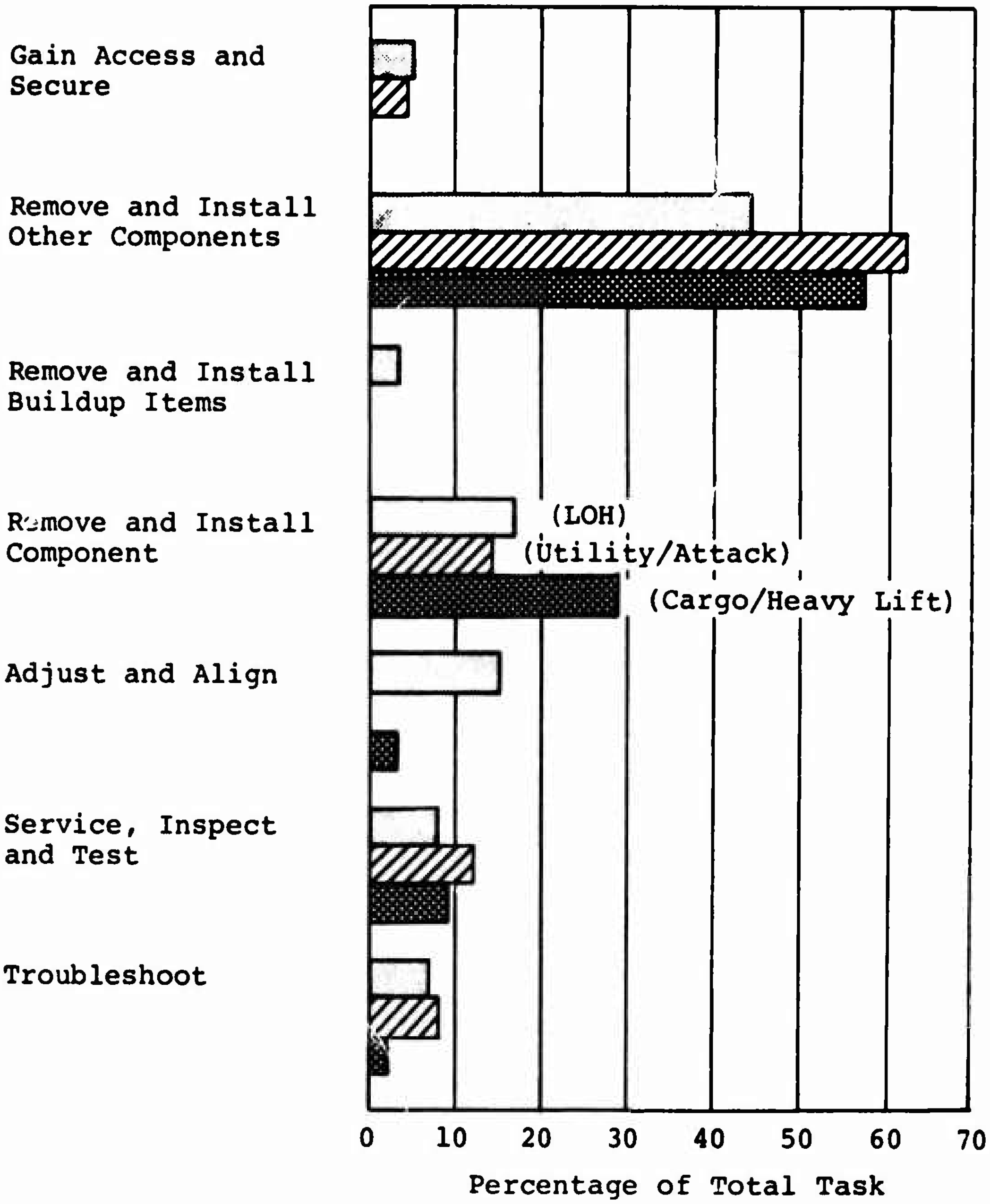


Figure 6. Component Replacement Time Distribution, Tail Rotor Gearbox.

in the latter part of this report.

## Related Design Concepts

Several candidates in the new concept category have been proposed for reducing the time required to remove and replace tail rotor drive shafts. These concepts, which also benefit replacement of the tail rotor gearbox, and the generic components under which they are found are listed below:

| Concept | Reference |
|---|---|
| Quick-Disconnect Tail Rotor Drive Shaft | Tail Rotor Drive Shaft and Hangers |
| Overcenter Coupling Clamp Latch | Tail Rotor Drive Shaft and Hangers |
| Telescoping Drive Shafts | Main Transmission |

## ENGINE-TO-TRANSMISSION DRIVE SHAFT

### REPLACEMENT TIME FACTORS

The bar chart of Figure 7 shows that the major contributors to replacement time for the engine-to-transmission drive shaft are gaining access, removing and installing the drive shaft itself, and preinstallation servicing.

#### Removal of Cowling and Fairing

Access to the engine-to-transmission drive shaft may require removal and installation of one or more of the following items: transmission fairing, engine intake fairing and engine cowling.

#### Removal of Baffles, Screens, Etc.

Access to the engine-to-transmission drive shaft may require removal and installation of one or more of the following items: engine air filter, drive shaft cover, shaft door and firewall seal, induction baffles, intake screen, and insulation.

#### Hand-Packing Lubrication

On one series of aircraft using fully crowned tooth, sliding spline type couplings, replacement shafts must be hand-packed with lubricant prior to installation. The quantity of lubricant is critical, making the procedure both exacting and time-consuming.

#### Shimming

In those installations employing length-sensitive couplings, the gap between the couplings and attaching flanges must be measured and shimmed as part of the shaft installation.

### STATE-OF-THE-ART SOLUTIONS

#### Particle Separators Integral With Engine

To avoid the type of installation where the engine air separator and filters partially enclose and obstruct access to the drive shaft, the separators and filters might be made integral with the engine and located aft of the drive shaft attach point. This would eliminate the need to remove the air particle separator and filters for replacement of the shaft, pro-

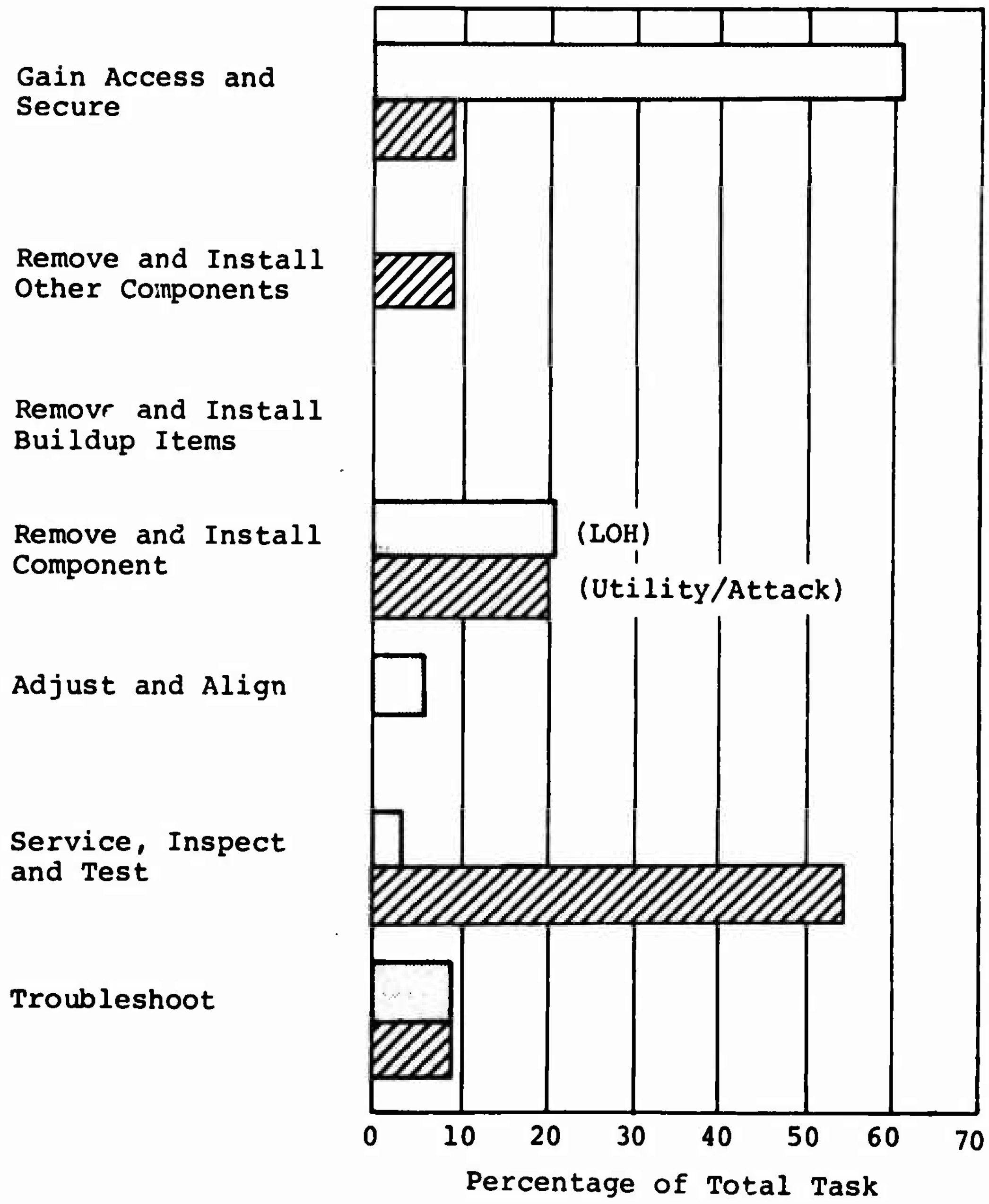


Figure 7. Component Replacement Time Distribution, Engine-to-Transmission Drive Shaft.

ducing a moderate man-hour savings. The reliability of the separator should improve due to less frequent disassembly, and the engine F.O.D. rate should also decline. Inspection of the shaft would be easier, and the separator could be designed with easily removable inspection plates for access to the inlet vanes and first stages of the compressor.

The weight and bulk of the engine would increase, however, with a detrimental effect on handling, packaging, shipping, etc. There may be an overall net reduction in aircraft weight, however. Many more separators would be required, i.e., one per engine rather than one per aircraft. The probability of developing a workable design is considered to be high.

Remotely Located Air Particle Separator

To avoid obstructing access to the engine-to-transmission drive shaft, the air particle separator might be located upstream from the engine inlet housing at the roofline or on the side of the fuselage. Access to the engine-to-transmission drive shaft would be greatly improved, eliminating the need to remove the air particle separator during shaft replacement and producing a substantial man-hour savings. Larger air inlet ducting may be required, however, and the separator may be larger and heavier. The efficiency of the separator may also be degraded due to the lower air velocity caused by the relocation. If the separator is a self-purging type, large pneumatic lines will be involved. The probability of developing a workable design is considered to be moderate.

Hinged Air Particle Separator

To facilitate access to the engine-to-transmission drive shaft, the engine air particle separator might be designed in two hinged halves. This would reduce the number of fasteners which need to be undone to gain access to the drive shaft, resulting in a small man-hour savings. Alignment (mating) of the separator halves would be facilitated. A small weight savings might result. When the upper half of the separator is hinged open, however, it would impede access to the shaft from the side on which the hinges are located. This might subject the separator to damage during maintenance of the shaft. The probability of developing a workable design is considered to be high.

Quick-Release Fasteners on Sheet Metal Parts

In some installations, interior sheet metal parts such as screws, covers and baffles must be removed to gain access to the engine-to-transmission drive shaft. The time to remove these items could be reduced in some cases through the use of

quick-release fasteners. The man-hour savings would be small and there would be a slight weight penalty.

Premeasured and Prepacked Lubricant

The fully crowned tooth, sliding spline type couplings used with engine-to-transmission drive shafts in some model helicopters must be hand packed with lubricant in critically prescribed amounts prior to installation. This time-consuming procedure could be facilitated by supplying the lubricant in premeasured packages. There would be a substantial reduction in the time required to apply lubricant at both initial installation and at the periodic lube interval. The special tool for spreading the lubricant could be eliminated. The potential for applying contaminated lubricant or lubricant in the improper amount would be reduced significantly. Lubricant provisioned in small packages would be more expensive, however.

Calibrated Lubricant Dispenser

The time-consuming lubrication of the fully crowned tooth, sliding spline type couplings might be facilitated by providing a calibrated lubricant dispenser in lieu of the special spreader now used. The dispenser would provide the required amount of lubricant and would eliminate the need to carefully distribute it within the coupling. A moderate time savings would be realized, but the potential for applying lubricant which is contaminated or not of the proper amount would remain about the same. An analysis of the importance of uniform lubricant distribution at initial installation would have to be made before adopting this procedure.

Non-Length-Sensitive Couplings

The time required to measure and shim couplings to obtain proper length adjustment might be eliminated through design of a non-length-sensitive coupling employing some type of slip-joint. A moderate man-hour savings would be realized from elimination of the length adjustment, but a coupling of this type would probably require lubrication, an added maintenance task. The non-length-sensitive coupling will weigh more, and inspection will be complicated because of the internal working (sliding) parts. The probability of developing an acceptable slip-joint design is considered to be moderate.

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing engine-to-transmission drive shaft replacement time in helicopters were those considered to be beyond the present state of the art as defined for this program. These concepts, described below, became candidates for the design study phase.

### Exposed Drive Shaft Installation

The time required to remove cowling and fairing to gain access to the engine-to-transmission drive shaft might be eliminated by aerodynamically contouring the transmission housing and engine frontal area to leave the drive shaft exposed. In addition to the man-hours saved at the time of drive shaft removal or installation, other components normally housed within the cowling would be more accessible for inspection, servicing and replacement. The transmission would become bulkier and heavier and more difficult to handle. Heat dissipation characteristics of the transmission may improve, but the aerodynamic characteristics of the helicopter would be degraded. The chances of damage to various components via environmental exposure or maintenance work in the area will be increased greatly. A net improvement in helicopter weight and cost might result. The probability of developing an acceptable design is considered to be moderate.

### Relocated Drive Shaft Attachment

The time required to remove engine intake baffles and screens, firewalls, etc., to gain access to the drive shaft attachment might be reduced by extending the attaching flange forward of these obstructions. A moderate man-hour savings would be realized at the expense of increased aircraft weight. Removal and installation of the engine may be complicated due to the added length of the output shaft housing and its penetration through the engine air induction compartment. Packaging and shipping of the engine would also be more expensive. The engine-to-transmission drive shaft would become shorter, thereby increasing the shaft operating angle for a given amount of engine-to-transmission offset. The probability of developing an acceptable design is considered to be moderate.

### Marmon Clamp Drive Shaft

The time required to disconnect the drive shaft from the engine output and transmission input in those installations using bolted attachments might be reduced by adopting the Marmon clamp, face-spline type attachment used in one series

of helicopters. The connection would be bulkier, heavier and substantially more costly than the bolted arrangement. The probability of developing a workable design is considered to be high.

## Flexible, Zippered Fairings

The time required to remove and replace such items as the engine air intake screens, baffles, etc., to gain access to the engine-to-transmission drive shaft might be reduced by using, in certain applications, flexible materials with zippered openings. For use as baffles, ducts, etc., in proximity to the shaft, they might be designed to be bent or collapsed simply out of the way. The flapping or flexing of resilient material could not be tolerated in the engine air induction areas, however, and zipper reliability is questionable. The probability of developing an acceptable design is considered to be low.

## Related Design Concepts

A number of design concept solutions having a potentially beneficial effect on the engine-to-transmission drive shaft are described elsewhere in this report. These pertain to components of the helicopter which have installation design problems in common with the engine-to-transmission drive shaft or which are physically or functionally connected to the shaft. These concepts and the generic components under which they are found are listed below:

| Concept | Reference |
| --- | --- |
| Flange-Mounted Engine | Engine |
| Gap-Compensating Mechanism | Tail Rotor Drive Shaft and Hangers |

## TAIL ROTOR DRIVE SHAFT AND HANGERS

The bar chart of Figure 8 shows that the major contributors to replacement time for tail rotor drive shafts and hangers are removal and installation of other components and removal and installation of the shafts and hangers themselves.

### Removal of Cowling and Fairing

Access to the tail rotor drive shafts may require removal and installation of one or more of the following items: transmission cowling, pylon access plates, tailpipe fairing, intermediate gearbox fairing, and hinged door on tail boom or fin.

### Removal of Support Bearings

In several models, the tail rotor drive shaft is removed with the bearings or hangers attached. The bearings or hangers must be transferred from the old to the new shaft before installation, or the shaft must be provisioned with bearings or hangers already assembled.

### Shimming

In some installations, the gap between the shaft and attachment flanges must be measured and shimmed prior to installing the shaft.

## STATE-OF-THE-ART SOLUTIONS

### Exposed Tail Rotor Drive Shaft

The time required to remove fairings and covers for access to the tail rotor drive shafts and hangers on some models could be eliminated by leaving the shafts and hangers exposed. Drive shaft accessibility will be optimized, facilitating inspection and producing a moderate man-hour savings at the time of replacement. The aerodynamic characteristics of the aircraft will be degraded, however, and the shafts and couplings will no longer be shielded from engine exhaust heat or rotor circulated debris. Exposed components will also be more vulnerable to corrosion. This type of design is currently employed successfully on one model of the LOH and is considered to have a high probability of successful application to other models.

### Quick-Disconnect Fasteners for Fairings

The time required to remove fairings and covers for access to the tail rotor drive shafts and hangers on some models could

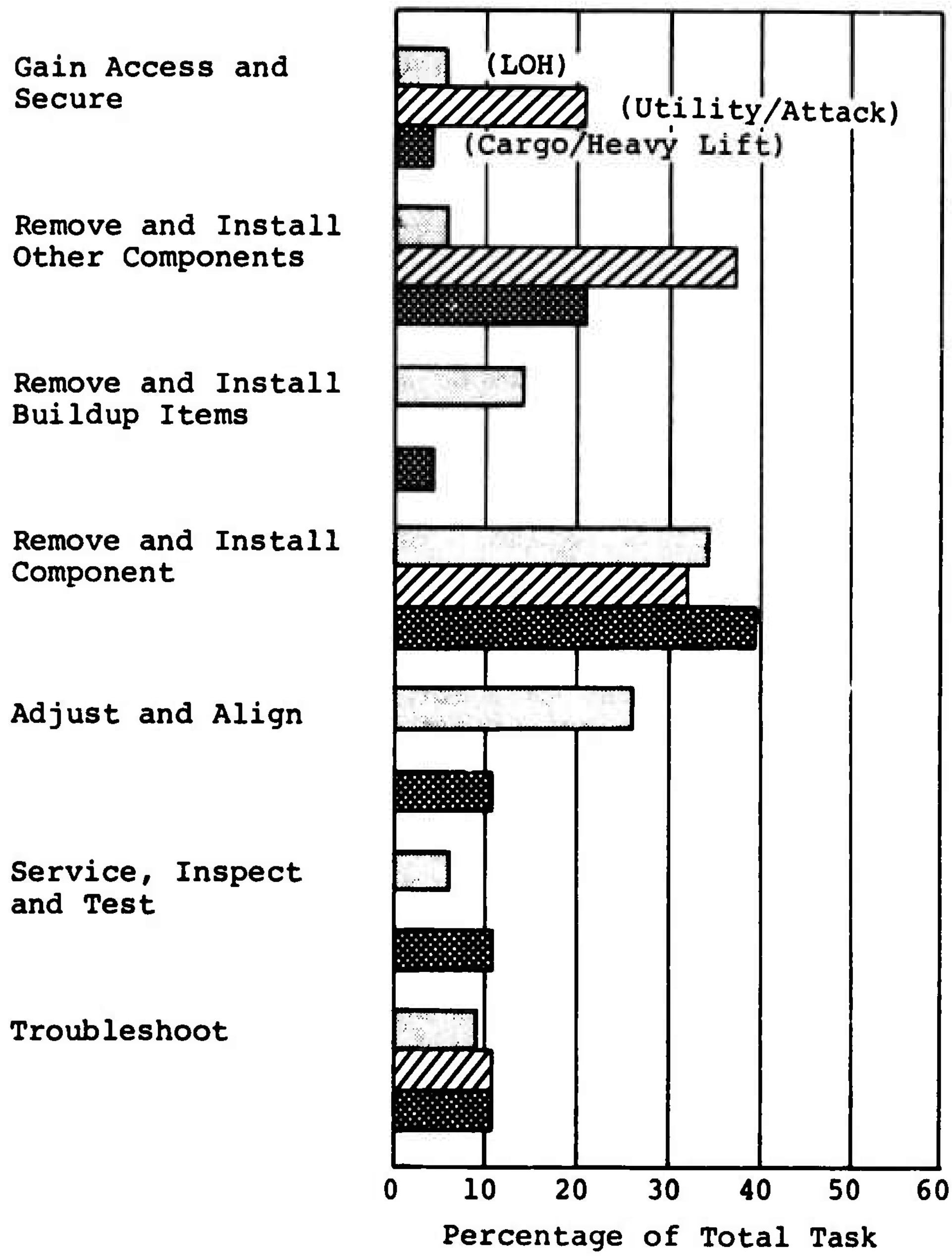


Figure 8. Component Replacement Time Distribution, Tail Rotor Drive Shaft and Hangers.

be reduced through the use of quick-release hinge/latch mechanisms. Used on both sides of the cover or fairing, access would be equally easy from either side of the aircraft, and complete removal from the aircraft would be facilitated. All hardware would be captive, eliminating loss and a potential source of F.O.D. A small weight penalty would be suffered.

Lift-Off Cover Hinges

The time required to remove covers and fairings for access to the tail rotor drive shafts and hangers in some models could be reduced through the use of lift-off hinges on both sides of the cover with a single fastener at the aft end. Complete access to the drive shaft would be attained by disconnecting the fastener at the aft end of the cover, pulling the cover aft about 1 inch, and lifting the cover off the tail boom. Lifting the cover from the tail boom may be a two-man job due to its length, and once removed, the cover will be subject to handling and maintenance damage. The probability of developing a workable design is high.

Unsupported Shaft With Split Damper-Type Bearings

In some installations, the tail rotor drive shaft is removed with the bearings or hangers attached and, if these items are not supplied with the assembly, swapped from the old to the new shaft. This task could be alleviated through design of a long, unsupported shaft with split, damper-type bearings. Elimination of hanger bearings and all but two couplings would greatly reduce tail rotor shafting maintenance, e.g., alignment, lubrication, bearing inspection, etc. There may be a weight savings. If the long shaft is made to pass through rather than above the tail boom, the tail rotor gearbox would have to be removed to replace the shaft, however. The long shaft would also pose packaging and shipping problems. Already employed on one model of the LOH, this design is considered to have a moderate probability of being applied successfully to other models.

Accurately Located Shaft Attachment Points

On two helicopter models, the gap between the attachment flanges and shaft must be measured and filled with shims, a time-consuming procedure. This task might be eliminated by accurately locating the shaft attach points and eliminating the shimming requirement. The concept could be applied to any shaft system utilizing length-sensitive couplings. The cost of maintaining close machining tolerances on the tail rotor gearbox, transmission and airframe attach fittings will

be substantial and perhaps prohibitive. The potential for incorrect installation of the shaft will be reduced. Extreme coupling angles will be greater. The probability of developing a technically acceptable design is considered to be moderate, although the cost-effectiveness of the concept is questionable.

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing the replacement time of tail rotor drive shafts and hangers in helicopters were those considered to be beyond the present state of the art as defined for this program. These concepts, described below, became candidates for the design study phase.

### Split-Type Hanger Bearings

In one installation, the tail rotor drive shaft hanger bearings are mounted in series on a long shaft section. Replacement of a failed bearing requires that the shaft be removed and, frequently, that one or more bearings be removed from the shaft to get to the failed bearing. Replacement of a failed hanger bearing could be vastly simplified if the bearing were split to avoid having to remove the shaft. The split hanger bearing is one of the twelve design study projects described in the latter part of this report.

### Quick-Disconnect Drive Shaft

The time required to disconnect the tail rotor drive shaft for replacement of the shaft or the several gearboxes to which it attaches could be lessened through design of a shaft quick-disconnect. The attachment scheme would have to be simple and foolproof to preclude improper assembly. The quick-disconnect would probably be bulkier and heavier than the existing connection, and shaft balance considerations may present design problems. The probability of developing an acceptable design is considered to be moderate.

### Overcenter Coupling Clamp Latch

One series of helicopters uses a Marmon type clamp and face splines on mating flanges to connect drive shafts. While less time-consuming to remove and install than bolted connections, a further simplification might be achieved by incorporating an overcenter latch on the clamp. This would eliminate the requirement to measure and equalize the gap at the two bolt locations securing the clamp halves and would produce a moderate man-hour savings. Inspection for security would be facilitated. The coupling will become bulkier and heavier, and a potential

safety problem exists in the possibility of the latch opening under centrifugal force. Very close tolerances will have to be held on all parts of the coupling. The probability of developing an acceptable design is considered to be moderate.

## Gap-Compensating Mechanism

On two models, the gap between the attachment flanges and shaft must be measured and filled with shims, a time-consuming procedure. This task might be eliminated by incorporating a gap-compensating mechanism in the shaft. This concept is one of the twelve design study projects described in the latter part of this report.

## Related Design Concepts

Two design concept solutions having a potentially beneficial effect on the tail rotor drive shafts and hangers are described elsewhere in this report. These pertain to the engine-to-transmission drive shaft, which has some installation design problems in common with the tail rotor drive shaft. The two concepts and the generic component under which they are found are listed below:

| Concept | Reference |
| --- | --- |
| Flexible, Zippered Fairings | Engine-to-Transmission Drive Shaft |
| Non-Length-Sensitive Couplings | Engine-to-Transmission Drive Shaft |

## ENGINE

### PEPLACEMENT TIME FACTORS

The bar chart of Figure 9 shows that the major contributors to engine replacement time in helicopters are removal and installation of other components, removal and installation of buildup items, and removal and installation of the engine itself.

#### Transferring Buildup Components

Many items must be removed from the old engine and mounted on the replacement engine during an engine change. These may include the starter generator, tachometer generator, freewheeling assembly, linear actuator, wiring harness, lines and hoses, tailpipe, fire shields, fire detector, etc.

#### Erection of Maintenance Hoist

A significant amount of time is devoted to erecting maintenance hoists, attaching slings, hoisting and maneuvering the engine and securing it to a transportation trailer or stand.

#### Rigging of Engine Control Linkage

Rigging of the engine control linkage must be checked after engine replacement.

#### Drive Shaft Alignment

Engine-to-transmission drive shaft alignment must be checked after an engine change.

#### Removal of Cowling and Fairing

Replacement of the engine may require removal and reinstallation of the following items: engine cowling, cowling support beams, tailpipe fairing, air inlet cowl, and transmission cowling.

#### Removal of Lines and Wires

Numerous fuel, air, and oil lines plus electrical wires must be disconnected and reconnected for an engine change.

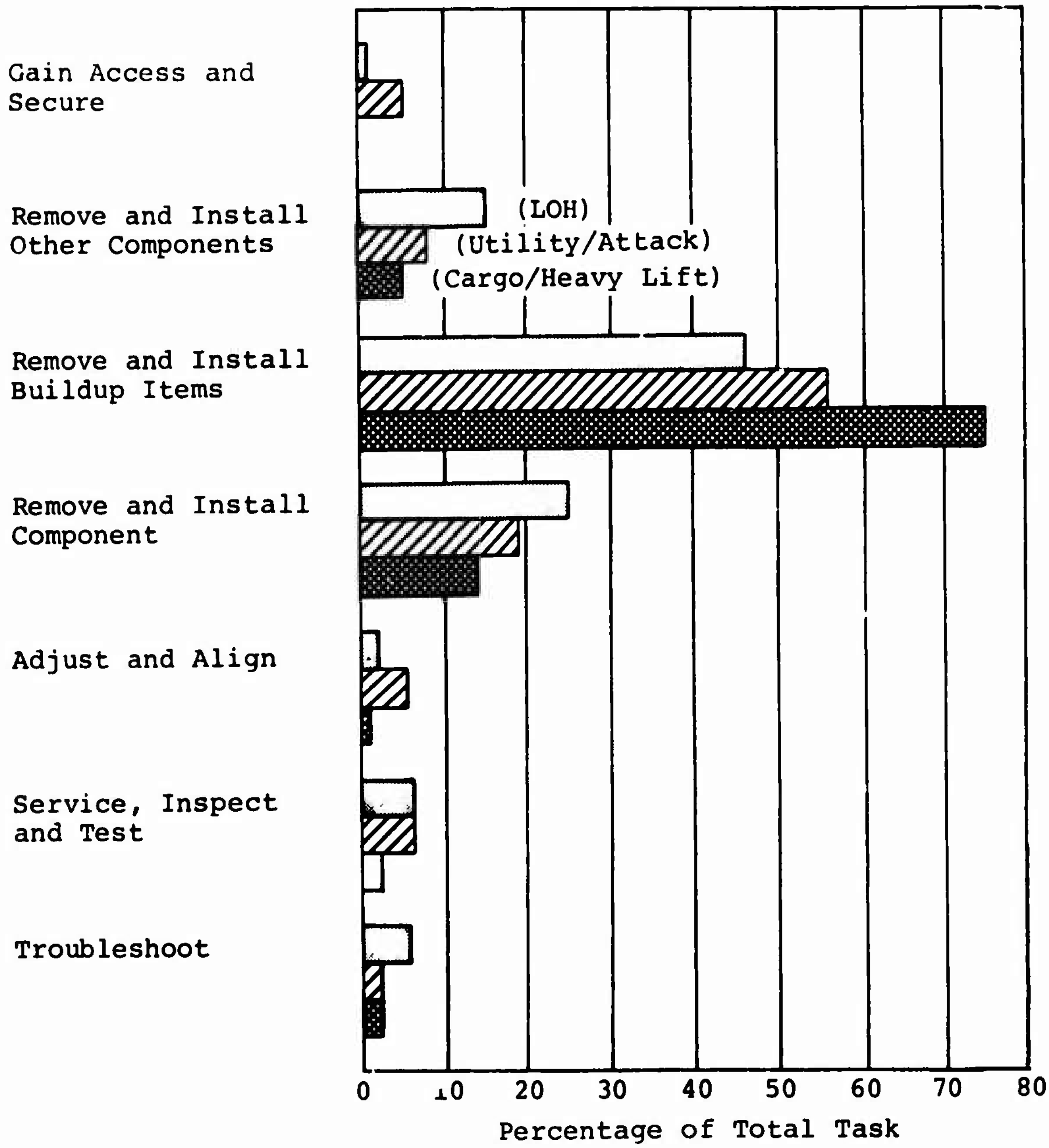


Figure 9. Component Replacement Time Distribution, Engine.

Handling

Considerable time is spent manually guiding the sling-suspended engine into position and aligning engine mounts, line connections, etc.

## STATE-OF-THE-ART SOLUTIONS

### Common Junction Points for Lines and Wires

The problem of guiding the engine into position could be lessened by terminating all lines and wires at a common and accessible junction point. This could eliminate the need to simultaneously observe and align many connection points while the engine is being guided to its mounts. Routine inspection would also be facilitated because all connections would be found at a single location. There would probably be a weight penalty due to the longer runs of lines and wires, however; and, unless the lines are manifolded and wires ganged in a common connector, the probability of cross-connections might be greater. A primary design problem would be to locate a mutually acceptable junction point which could accommodate the several installations for which a given engine might be used. Pod-mounted or tray-mounted installations might require a modular approach to line and harness installations. If cost and weight penalties are shown to be acceptable, the probability of developing a feasible design is considered to be high.

### "V" Band Attachment of Accessories

The time required to transfer buildup items to the replacement engine might be reduced by attaching certain accessories with a "V" band coupling in lieu of the bolted attachments primarily used. This substitutes one fastener for several but incurs moderate weight and cost penalties due to the addition of a flanged adapter to the housing on which the accessory is mounted. It would eliminate the need for cumbersome "crow's foot" wrenches where they are now required and would also eliminate the possibility of stripping threads or studs. The "V" band approach suffers one major deficiency in that, unlike accurately torqued bolts, proper seating is accomplished by tapping around the circumference of the coupling until it "feels" secure, a less positive verification of proper installation. In order to adopt the "V" band concept, changes to engine accessories and mounting pads would be necessary. Already used for the installation of light aircraft generators,

the probability of successful application to other types of accessories is high.

Overcenter Latch for "V" Band Clamps

The "V" band clamps used to secure such items as tailpipes, inlet ducts and fire shields might be made easier to remove and install by replacing the present bolt and rod connection with an overcenter latch mechanism. Tolerances on the mating flange thickness and chamfers and on the length of the "V" band would have to be closely held. The "V" band and brackets to which the latch attaches would have to be stronger than present to accommodate the large momentary tensile load imposed when the latch goes "overcenter". Weight and cost would rise slightly. The amount of adjustment required in the latch would have to be determined, and provisions would have to be made to compensate for temperature variations. The probability of developing a useful design, assuming acceptable weight and cost increases, is considered to be high.

Optical Fire Detector

The time required to transfer fire-sensing elements to the replacement engine could be eliminated through the use of an optical fire detector. Reliability should be better and maintenance damage would be less frequent. A weight savings might result. Since an optical sensor would respond to light rather than temperature, fewer false indications of fire should be experienced. The concept would not be applicable to engines which are not cowled or are otherwise exposed to sunlight. Being able to locate the sensor for complete surveillance of the fire zones in a manner that would not subject it to sunlight exposure is essential. If the trade-offs with other factors are satisfactory, the probability of developing a successful application is high.

Modularized Engine

Modular approaches to engine design, which are currently being developed by the engine industry, will reduce substantially the time expended on engine changes. In one such approach, the engine is removed with all accessories installed and sent to a local shop for replacement of the discrepant module. The replacement engine drawn from supply has all engine accessories already assembled. Maintenance is reduced on the line and also at depot level because only the discrepant module, not the entire engine, is returned for repair. Shipping costs will be lower and the value of components in the supply pipeline will be substantially reduced. It is expected that

modular engine designs will be introduced to service in the near future.

## Complete Engine Assembly

One straightforward but obviously costly solution to the heavy maintenance time expended on engine buildup is to provide engines as complete assemblies, i.e., with all accessories already installed. The substantial man-hour savings and reduced downtime realized at the time of engine replacement would probably not justify the large cost penalties inherent in this approach, however. Increases in the weight and envelope of the engine will add to shipping and inventory costs. The replacement interval for relatively reliable accessories is reduced arbitrarily to that of the entire engine. Other costs such as the added burden placed on the higher maintenance levels must also be considered. The concept involves no new approach to design but simply a change in logistics policy.

## Integral Lifting Lugs and Sling Supports

A small man-hour savings could be made at the time of engine change by eliminating the need to bolt lifting devices to the engine. Integral lifting lugs and sling supports could be made part of the basic engine at an increase in weight and cost. The integral lifting provisions would somehow have to accommodate center-of-gravity shifts created by different engine configurations and level of buildup. Although technically achievable, this concept amounts to flying support equipment with the aircraft and is not highly attractive economically.

## Close-Tolerance Engine Mount Pads

The requirement to check, and perhaps adjust, alignment of the engine-to-transmission drive shaft after an engine change might be eliminated by closely controlling the location of the engine mount pads. This would, in effect, make replacement of an engine equivalent to reinstalling the old engine and, providing no changes were made in the transmission or shaft locations, would make an alignment check unnecessary. To accurately control the location of the mount pads in relation to the engine output shaft, however, it would probably be necessary to replace and machine the mount pads after engine assembly whenever components of the engine affecting this relationship were changed at depot. A cost trade-off would be needed to assess the desirability of adopting this approach.

## Accurate Engine and Transmission Locations

The need to check and align the engine-to-transmission drive shaft after either an engine or a transmission change might be eliminated if the location of component and airframe mounting points could be precisely controlled. As with the previous proposal, however, this probably would require machining new mount bosses on the engine and transmission at each overhaul assembly. The problem is further compounded by the need to maintain accurate relationships between airframe mount locations which may be more difficult to hold. Although technically feasible, economics may rule against such an approach.

## Elimination of Nonfunctional Cowling

The man-hours required to remove and reinstall cowling and fairing to perform an engine change could be reduced in some cases by eliminating nonfunctional cowling and fairing in the engine area. In addition to reducing the work of an engine change, inspections and other maintenance of the engine would be facilitated. Ambient temperature in the engine compartment may be reduced, with a corresponding improvement in engine performance. The weight of the helicopter would be reduced but at some degradation in aerodynamic and aesthetic qualities. Exposure of the engines, especially in low-profile aircraft, will permit entry of dust and rain which may cause corrosion and cleanup problems. Uncowled engines are currently found on one model in the cargo/heavy lift class of helicopters and could be readily adapted to other models if the disadvantages were not found to be unacceptable.

## Quick-Release Cowling and Fairing

The time required to remove and reinstall cowling and fairing for an engine change could be reduced through the use of quick-release ball-lock pins. Fewer ball-lock pins would be required than the threaded or quarter-turn fasteners commonly used, and the need for tools would be eliminated. Problems with stripped and damaged fasteners should also be fewer. Ball-lock pins may add weight and degrade aerodynamic characteristics. Applying this method of cowling attachment would depend on selecting the minimum number of fasteners and their location to obtain the required security.

## Sliding Engine Cowls

The need to detach and remove engine cowling from the aircraft to perform an engine change might be avoided in some helicopter

configurations through design of sliding cowling which remains with the aircraft after exposing the engine. Leaving the cowling attached to the aircraft will reduce handling damage and the problems associated with numerous small fasteners. If the cowling can be made to operate easily, many small panels and doors used for inspection and maintenance might be eliminated, reducing the overall cost and weight of the cowling. The slides, rollers and latches will probably be less reliable than fixed fasteners, however. Already used on one commercial light helicopter, application of the sliding cowling concept will depend on such considerations as overall system geometry, the design of support members, and the ability to design adequately for normal handling and wind loads.

## Multiwire Single Electrical Connector

The time involved in disconnecting and reconnecting electrical wires for engine replacement could be reduced through the use of a multiwire single connector electrical wiring system. In order for all wires to terminate at one location, some would have to be made longer. The location of the single-point connector must be selected for ease of access and adequate work space.

## Manifold Connectors

The use of single-point, manifold connectors would reduce the time required to disconnect and reconnect engine air, fuel and electrical lines for replacement of an engine. Cross-connection of lines would be impossible, and inspection of the most frequently disconnected points in the lines (where leaks are most prevalent) would be facilitated. The manifold connector would be heavier and, in order for all lines to terminate at a single location, the lines would tend to be longer and heavier as well. Line routing, location of supports, alignment and sealing of fittings, and access and work space at the manifold would have to be considered.

## Integral Lube System

The time involved with the interface of the engine and its external lube system during engine replacement could be reduced if the lube and lube cooling system could be made integral with the engine. The oil cooler blower might be driven by compressor air through a short run of flex hose or directly from the accessory drive gearbox, eliminating the troublesome flex coupling. The integral system would eliminate most external lines and the need to disconnect or transfer them for an engine change. Because the lube system would be confined and housed internally, it should be more reliable and less

vulnerable to external damage.

The weight and cost of the engine will increase, but the overall result may be an aircraft weight and cost reduction. Shipping costs for the bulkier and heavier engine would increase. The desirability of the concept would have to be analyzed through a trade-off study and would probably be least attractive for pod-mounted engine installations in which envelope and frontal area assume great importance.

Related State-of-the-Art Solutions

Two state-of-the-art concepts proposed for improving the replacement time of engine fuel controls also have a potential benefit for engine replacement:

| Concept | Reference |
|---|---|
| Bench-Rigged Fuel Control | Fuel Control |
| Increased Dwell Band Width | Fuel Control |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing engine replacement time in helicopters were those considered to be beyond the present state-of-the-art as defined for the program. These concepts, described below, became candidates for the design study phase.

### Quick Attach/Detach for Accessories

The time required to transfer accessories to the replacement engine could be reduced through the application of a quick attach/detach (QAD) mechanism for accessories. This concept is one of the twelve design study projects described in the latter part of this report.

### Electronic Tachometer Pickup

Tachometer generators are one of the engine accessories involved in engine buildup. The time devoted to transferring this accessory could be reduced substantially or eliminated entirely by substituting an electronic pickup for the mechanically driven tach generator. The sensor could be very small and easily attached to the engine. It would have no moving mechanical parts and should therefore improve reliability. The rotating trigger would be built into the engine and would

not be subject to handling by the mechanic. Shaft seal problems would be eliminated. There would be a moderate weight savings, and cost would be lower if the device received widespread application. The technology required to apply the concept presently exists if such design factors as sensor location and phase relationships can be resolved.

Cowling and Fairing Assembled as a Removable Unit

Removal and reinstallation of cowling and fairing for an engine change could be simplified if all cowlings and fairings were locked into an independent support structure attached to the airframe by quick-removable pins or latches so that the entire assembly could be removed as a single unit. Time would be saved in not having to release numerous fasteners and not having to handle individual pieces of cowling and fairing. The reliability of fasteners used on individual cowls or fairings would improve due to less frequent use, as should the reliability of the entire structure. A hoist would probably be needed to lift the assembled unit from the aircraft. Although considered technically feasible, a thorough study of weight and cost factors would be needed to evaluate the desirability of this concept.

Hinged and Hydraulically Operated Cowling

One approach to the problem of having to remove extensive cowling and fairing to replace an engine would be to provide a large cowling above the engine deck, hinged at the bottom and hydraulically operated to open in "clamshell" fashion to form work platforms. The cowling would provide complete access to the engine, transmission and adjacent components as well as integral work platforms. The concept would add significantly to helicopter weight and could not easily be incorporated in low-silhouette helicopters having short rotor masts. The hydraulic system for the cowling would itself require maintenance. The added weight, cost and maintenance of the system would have to be traded off against the reduction in cowling pieces and improved access it provides. Success probability is considered to be low to moderate.

Hinged Frame for Engine Handling

Currently, engines are hoisted out of and into the aircraft via a special maintenance hoist mounted on the aircraft or an external hoist or crane. The first is very time-consuming to erect, and the latter is not always available. One approach to this problem would be to design a hinged frame or other structural member of the aircraft to function in combination with

block and tackle as an integral davit. The concept would have application only to those aircraft which have pod-mounted engines with substantial structure above the engines. The tandem-rotor cargo class helicopter in the present inventory might lend itself to this concept. The integral davit would incur both weight and cost penalties and, unlike other portable maintenance hoists, could not be used on components other than the engine. Design factors would include the geometry and strength of the davit and the clearances between the engines and useable structure. The concept is considered to have very limited application but a moderate probability of being successful where the necessary design requisites are present.

## Fuselage Tracks for Pod-Mounted Engines

Currently, engines are hoisted out of and into the aircraft via a special maintenance hoist mounted on the aircraft or an external hoist or crane. The first is very time-consuming to erect, and the latter is not always available. For pod-mounted engine installations, this problem might be approached by designing tracks into the fuselage on which the engines could be rolled into and out of their installed position. The tracks would terminate at a point and in a manner that would precisely control the installed position of the engine. Small engines might be moved on the tracks manually, while block and tackle would be necessary for heavier engines. The tracks would add weight and might degrade the aerodynamic cleanliness of the fuselage. Two sets of mount bosses would be required on the engine: one for attachment of track rollers and the other for attachment to the transportation trailer. Costs would increase. Design factors would include track attachment and geometry, structural clearances, and the ability to achieve the required strength, weight and simplicity. The concept is considered to have very limited application but a moderate probability of being successful where the requisite design factors are present.

## Engine Rails

The difficulty experienced with manually guiding the sling-suspended engine into position while aligning the mounts, line connections, etc., could be eliminated substantially if the engine were designed to slide on rails or tracks into its installed position while simultaneously coupling all required fluid and electrical connections. The design should be such that the engine, when slid to the limit of the tracks, would be positioned precisely relative to the transmission, thus assuring engine-to-transmission drive shaft alignment. The

rolling or sliding elements would serve also as the engine mounts. Rails or tracks similar to those in the aircraft could be incorporated in the transportation trailer or canister so that the rollers and latches could remain with the engine. The concept would add weight and cost to the helicopter. Design problems would include engine mount and guide rail geometry, provisions for mating the engine with the guide rails, manifold design and location, etc. The concept was selected originally as one of the twelve design study projects to be pursued from the standpoint of a fuselage-mounted engine installation. The concept eventually developed into one that employs vertical arches instead of rails for application to pod-mounted engine installations and is described in the latter part of this report.

Increased Misalignment Coupling

The time involved in checking and adjusting engine-to-transmission shaft alignment after an engine change could be eliminated by designing a flexible coupling which could tolerate as much misalignment as might be present with the normal tolerances at engine and transmission mount points, shaft connections, etc. This would require a major design innovation in mechanical couplings and is considered to have a low probability of success.

Built-In Shaft Alignment Indicator

A considerable amount of time is expended checking and aligning the engine-to-transmission drive shaft following an engine change. Much of this time is consumed in setting up and using the special tools and indicators with which shaft alignment must be checked. The task could be greatly facilitated if a rapid and positive indicator of shaft alignment could be built into the aircraft. This concept is one of the twelve design study projects described in the latter part of this report.

Flange-Mounted Engine

The time required to check and align the engine-to-transmission drive shaft following an engine change would be eliminated if the engine were flange-mounted directly on the gearbox with no connecting flexible shaft. This concept is one of the twelve design study projects described in the latter part of this report.

Air Bearings

The maintenance associated with the engine lube system might be eliminated by incorporating air bearings (thrust and radial) in the engine and doing away with the oil system. Engine and helicopter weight and cost would decline significantly. An extensive test and development program would be required to establish the feasibility of using air bearings in engine applications.

Related Design Concepts

Two other design concepts having a potentially beneficial effect on the time to replace engines are covered elsewhere in this report. These pertain to components of the helicopter which are physically or functionally connected to the engine. The concepts and generic components under which they are found are:

| Concept | Reference |
|---|---|
| Control System Trim Mechanism | Fuel Control |
| Relocated Drive Shaft Attachment | Engine-to-Transmission Drive Shaft |

## ENGINE FUEL CONTROL

### REPLACEMENT TIME FACTORS

The bar chart of Figure 10 shows that the major contributors to replacement time for the engine fuel control are tasks associated with removal and installation of the fuel control itself.

#### Rigging of Fuel Control Linkage

Rigging of the engine controls must be checked after replacement of the fuel control, a procedure which frequently requires the use of special tools and the expenditure of considerable maintenance time.

#### Mounting Stud Inaccessibility

In some installations, the attaching studs are relatively inaccessible and considerable time is expended removing, installing and torquing self-locking nuts.

### STATE-OF-THE-ART SOLUTIONS

#### Fuel Control Attaching Nuts

The problem of attaching stud inaccessibility could be partially overcome through the use of free-spinning, self-locking nuts to attach the fuel control to the engine. This would allow the nuts to be turned by hand to the point of seating instead of using a wrench or in some cases a "crow's foot". The nuts would be slightly heavier and more expensive.

#### Increased Dwell Band Width

The need to check the rigging of the engine controls after replacing the fuel control might be eliminated if the dwell bands at cutoff, ground idle, flight idle, military and takeoff power could be made sufficiently broad to accept rigging variations. There would be a slight weight penalty. The width of the dwell bands and the effect of reduced power level travel on engine performance and control response would have to be studied. The concept is considered to have a high probability of success.

#### Related State-of-the-Art Solutions

One state-of-the-art concept having a potentially beneficial

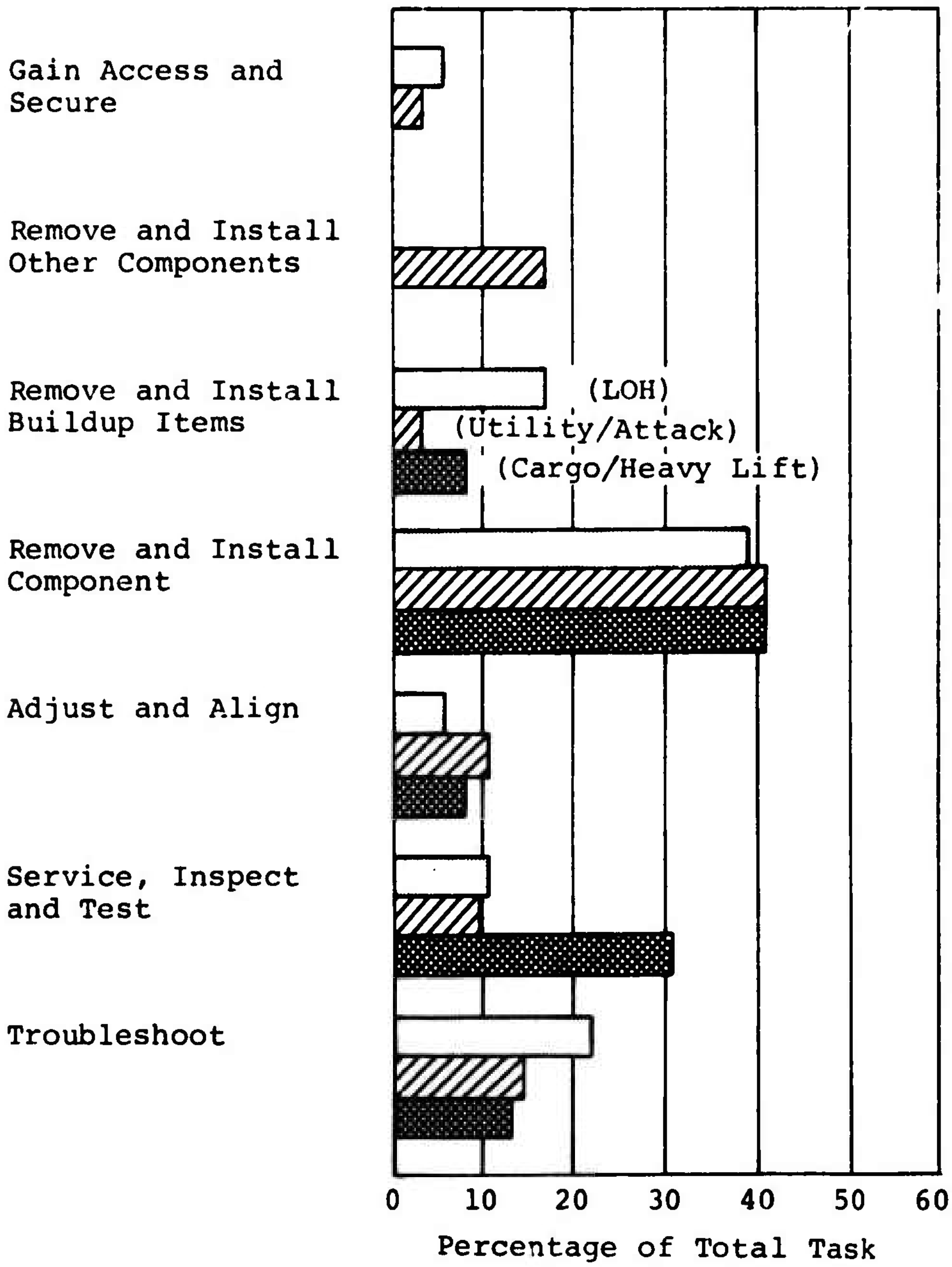


Figure 10. Component Replacement Time Distribution, Engine Fuel Control.

effect on the replacement of engine fuel controls is described elsewhere in this report. The concept and generic component under which it is found are:

| Concept | Reference |
|---|---|
| "V" Band Attachment of Accessories | Engine |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing fuel control replacement time in helicopters is one considered to be beyond the present state of the art as defined for this program. This concept, described below, became a candidate for the design study phase.

### Control System Trim Mechanism

The time expended in the rigging of engine fuel controls might be eliminated by incorporating a trim mechanism in the engine control system to compensate for tolerance variations between fuel controls. This concept effectively transfers the rigging function from the mechanic to the pilot at a significant expense in weight, cost and system complexity. The components of the trim system (actuator, control switch, etc.) will themselves generate maintenance. Safeguards would be needed to prevent the disturbance of control system rigging by inadvertently actuating the cockpit switch. The system could conceivably operate electrically, hydraulically or mechanically. The location and sensitivity of the trim mechanism would be important design factors. The concept is considered to have a moderate probability of being developed technically, but its value appears doubtful from an economic standpoint.

### Related Design Concepts

One design concept candidate having a potentially beneficial effect on the replacement of engine fuel controls is described elsewhere in this report. The concept and generic component under which it is found are:

| Concept | Reference |
|---|---|
| Quick Attach/Detach for Accessories | Engine |

## MAIN ROTOR BLADE

### REPLACEMENT TIME FACTORS

The bar chart of Figure 11 shows that the major contributors to replacement time for the main rotor blade are removal and installation of the blade itself and post-installation adjustment and alignment.

#### Retention Bolt Seizure

Main rotor blade retention bolts frequently seize and are difficult to remove.

#### Blade Handling

On medium and heavy class helicopters, the size and weight of the main rotor blades and their installed height from the ground require the use of special handling aids and two or more people for removal and installation.

#### Rotor Tracking

Replacement of a main rotor blade requires that rotor track be checked and adjusted.

### STATE-OF-THE-ART SOLUTIONS

#### Nonseizing Retention Pins

The time involved in freeing blade retention pins which have seized in the blade grip and root bushings might be alleviated through design of pins and bushings which are not susceptible to seizing. This might be accomplished through the specifications for pin and bushing materials and/or the incorporation of a non-self-energizing taper on the pin.

#### Expandable Bushing Pins

Another approach to reducing the time involved in the removal of seized blade retention pins would be to employ an expandable bushing concept for blade-to-grip attachment. This concept, already used successfully on one of the LOH models, minimizes the number of pieces of attaching hardware and eliminates the need for pin pullers, special sockets, torque wrenches, etc.

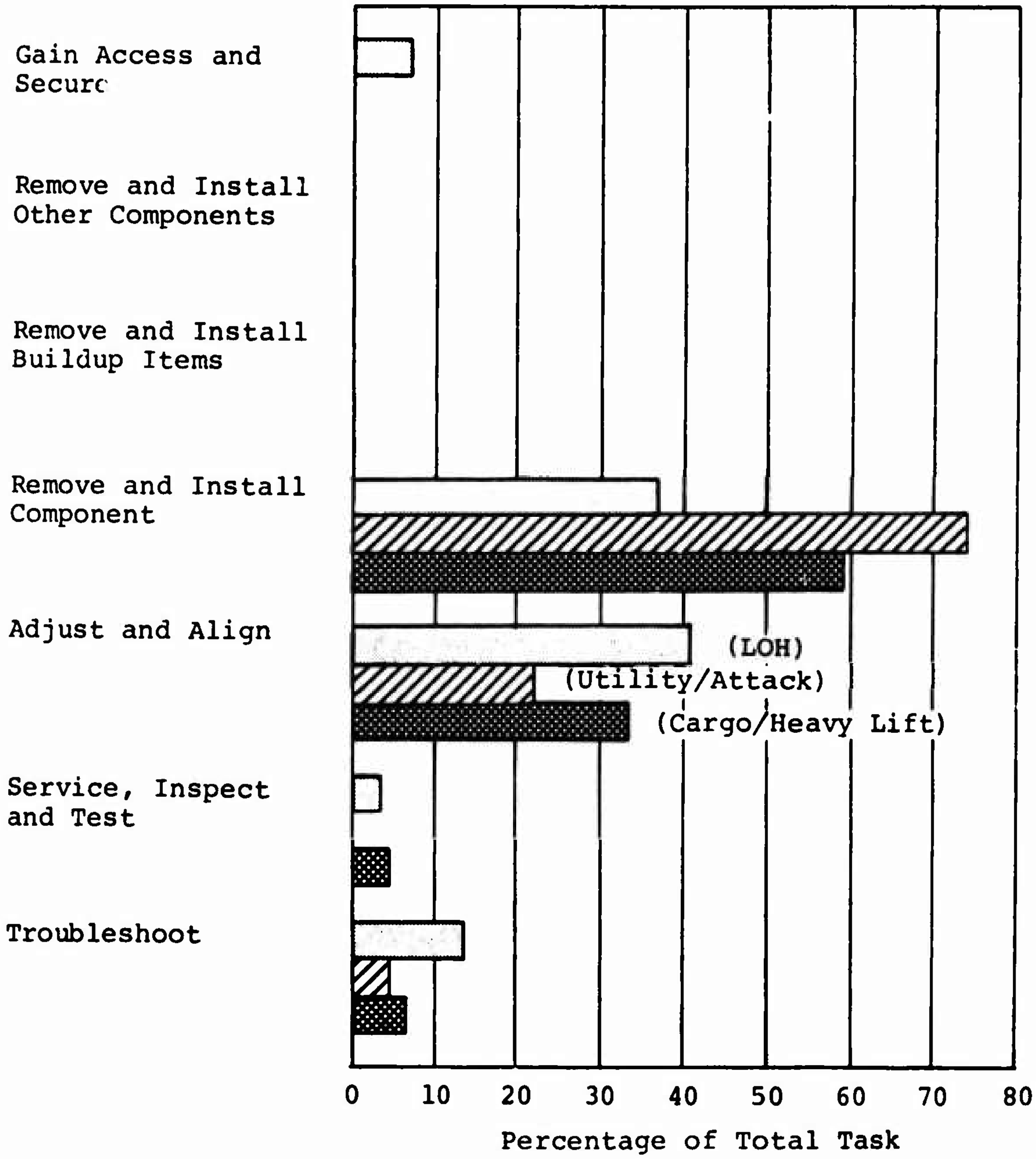


Figure 11. Component Replacement Time Distribution, Main Rotor Blade.

The expandable bushing allows for looser tolerances in the grip bore and eliminates the possibility of pin seizure. The concept could also be used to install lead/lag dampers in those installations utilizing them. Some of the potential disadvantages of the expandable bushings are the high hoop stresses and radial deflection they induce. Since the bushings tend to apply a radial preload to the lag bearings, they should be used only on the pin-housing side of the hinge. The application of expandable bushings for rotor blade retention would require a thorough analysis of blade loads, stress levels, etc. The concept is considered to have a moderate probability of succeeding in certain applications.

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing the replacement time for main rotor blades in helicopters were those considered to be beyond the present state of the art as defined for this program. The concepts, described below, became candidates for the design study phase.

### Main Rotor Blade Quick Attach/Detach

The time required to remove and install helicopter main rotor blades could be reduced through design of a quick attach/detach mechanism. This concept is one of the twelve design study projects described in the latter part of this report.

### Increased Blade Droop Limit

The difficulty of handling main rotor blades during removal and installation might be alleviated if the blade droop limit could be increased to allow the blade tip to be supported from the ground. This would eliminate the need to hold the blade in a horizontal plane for removal from or attachment to the grip or retention. Its disadvantages include having to provide a hand-held support for lowering the blade tip to the ground and the continued need for a hoist to lift the inboard end of the blade. The rotor system would also become heavier and more complex. The probability of developing a successful design is considered to be low to moderate.

Pylon-Mounted Blade Cradle

When replacing the main rotor hub, swashplate or transmission, the rotor blades are removed and lowered to the ground. The time required to handle the blades between the aircraft and the ground might be eliminated through design of a built-in cradle which would temporarily support the rotor blades when disconnected from the hub. One such approach would be to provide an extendable cradle on the tail rotor pylon which would support the tip of the blade with corresponding provisions on the main transmission housing or adjacent structure for the grip end of the blade. When the blades are removed to gain access to another component such as the hub, they would be disconnected and supported in the cradle on the aircraft, eliminating much handling time and the need for external blade racks. The concept would add weight and complexity to the helicopter and may be impractical for blades heavier than can be carried by two men. Because of the many factors related to helicopter configuration, rotor geometry, etc., which would have to be satisfied to pursue this concept, it is considered to have a low success probability.

In-Flight Rotor Tracking

The considerable time expended on checking and adjusting rotor track after replacement of major main rotor components might be reduced substantially through incorporation of an in-flight rotor tracking system. This would eliminate the need for maintenance personnel to manually track blades with tracking flags, strobe lights, etc. By allowing the pilot to compensate for track changes in different flight regimes, it will lower the average aircraft vibration level, resulting in an overall improvement in system reliability. On the negative side, an in-flight tracking system will add to the complexity, weight and cost of the aircraft and introduce new components which in themselves will require maintenance. Overall, a net decrease in maintenance man-hours would probably be realized, however. In-flight rotor tracking is presently used in one type of helicopter employing a rotor control system which operates under very low control forces. The feasibility of applying in-flight rotor tracking to other types of rotors would require a substantial design investigation.

Rotor Track Sensor System

Another approach to reducing the time required for main rotor tracking would be to incorporate in the aircraft only the sensor portion of an in-flight rotor tracking system. In lieu

of manual tracking flags or strobe light devices, on-board sensors would identify, during ground runup or flight, an out-of-track blade and display the direction and extent of control system adjustment needed to bring the blade into track. Although this system would also add complexity, weight and cost to the aircraft, unlike the fully automated system described previously, it would not introduce the heavy and costly components (motors, actuators, etc.) needed to adjust rotor track from the cockpit. Evaluating the feasibility of this concept would also require a substantial design study effort.

## MAIN ROTOR HUB

### REPLACEMENT TIME FACTORS

The bar chart of Figure 12 shows that the major contributors to replacement time for the main rotor hub in helicopters are removal and installation of other components and removal and installation of the hub itself.

#### Removal of Rotor Blades

Replacement of the main rotor hub on all helicopter models requires removal of the main rotor blades.

#### Use of Special Tools

On several models, replacement of the main rotor hub requires the use of several special tools. The setup, use and teardown of these items contribute to the maintenance time.

#### Rotor Track Requirement

Because replacement of the main rotor hub requires removal of the main rotor blades and disconnection of the rotor controls, rotor track must be checked and adjusted.

#### Erection of Maintenance Hoist

When neither a mobile hoist nor an overhead crane is available, a portable maintenance hoist, mounted on the aircraft, must be used. Erection and dismantling of the hoist are time-consuming.

### STATE-OF-THE-ART SOLUTIONS

#### Bolt-On Hub

The time involved with the use of special tools to remove and install the main rotor hub on some models could be reduced by designing the hub to bolt onto the rotor mast. Although presenting no unusual design problems, the small man-hour reduction that this concept could effect may not offset other possible penalties in such areas as weight and cost.

#### Related State-of-the-Art Solutions

A number of state-of-the-art concepts related to improving the replacement time for main rotor blades will also benefit main

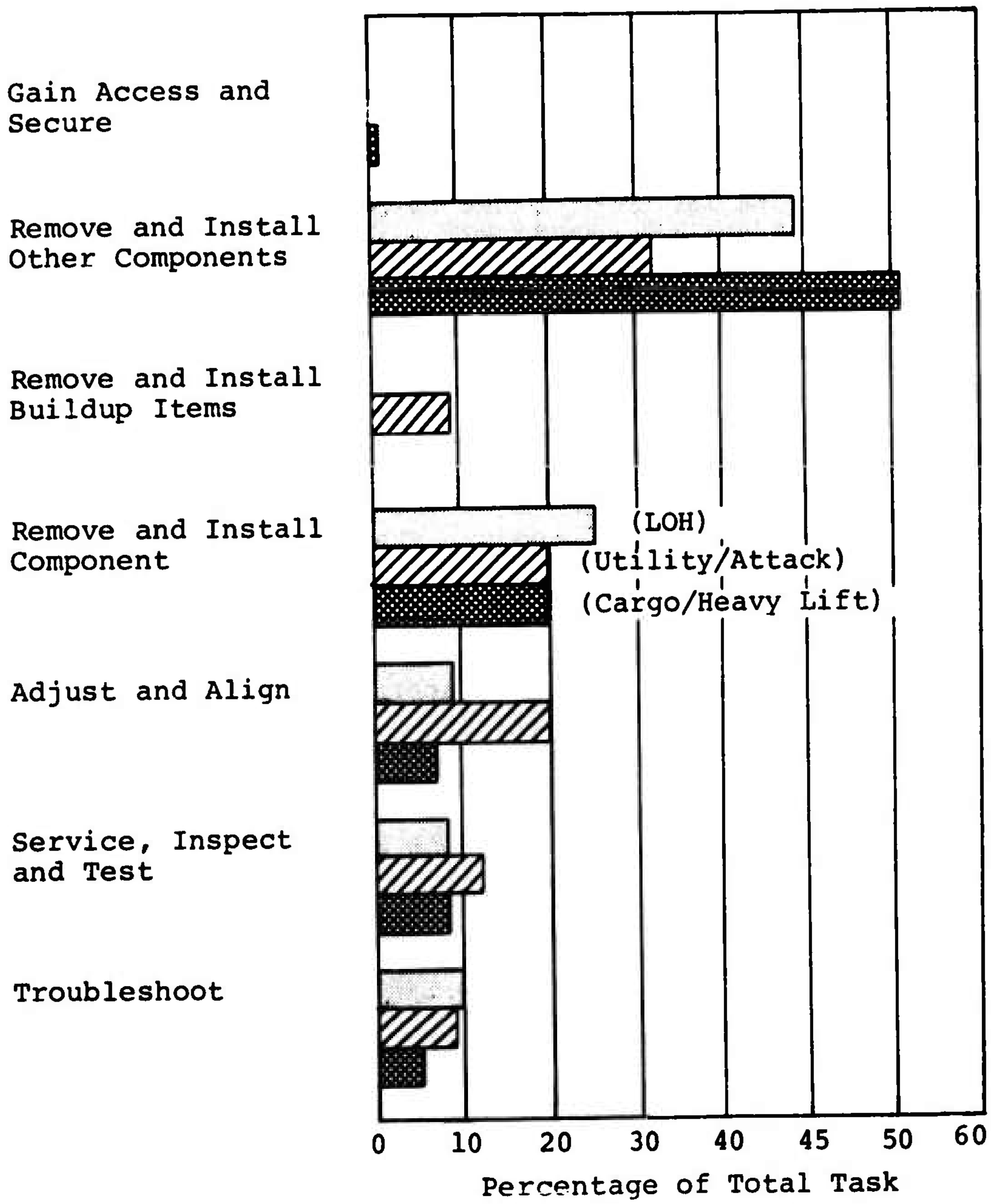


Figure 12. Component Replacement Time Distribution, Main Rotor Hub.

rotor hub replacement. These concepts and the generic component under which they are found are listed below:

| Concept | Reference |
|---|---|
| Nonseizing Retention Pins | Main Rotor Blade |
| Expandable Bushing Pins | Main Rotor Blade |

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing main rotor hub replacement time in helicopters is one considered beyond the present state of the art as defined for this program. This concept, described below, became a candidate for the design study phase.

### Simplified Retention-to-Hub Attachment

The time required to remove and reinstall the main rotor blades for replacement of the rotor hub could be reduced by simplifying the connection between the hub and blades. This might be in the form of a modularized hub with a simple bolted connection which would allow the blade retention to remain attached to the blade, avoiding the more difficult task of pulling the blade attaching pins. The hub would become more complex and probably increase in size with some attendant penalty in aerodynamic drag. Although probably feasible from the technical standpoint, the disadvantages associated with this concept may militate against its implementation.

### Related Design Concepts

A number of installation design concepts related to replacement of main rotor blades in helicopters will also benefit main rotor hub replacement. These concepts and the generic component under which they are found are listed below:

| Concept | Reference |
|---|---|
| Pylon-Mounted Blade Cradle | Main Rotor Blade |
| Increased Blade Droop Limit | Main Rotor Blade |
| In-Flight Rotor Tracking | Main Rotor Blade |
| Rotor Track Sensor System | Main Rotor Blade |

## TAIL ROTOR BLADE

### REPLACEMENT TIME FACTORS

The bar chart of Figure 13 shows that the major contributors to replacement time for tail rotor blades in helicopters are removal and installation of the blade itself and post-installation rigging and adjustment.

#### Blades Not Replaceable on Aircraft

In most helicopter models, the tail rotor blades and hub must be removed from the aircraft prior to removal of the blade from the hub.

#### Balancing

On one series of helicopters, replacement of a tail rotor blade requires balancing of the tail rotor assembly.

#### Tracking

On some helicopter models, replacement of a tail rotor blade requires tracking of the tail rotor and making controls rigging adjustments.

### DESIGN CONCEPT CANDIDATES

Two installation design concepts proposed to reduce the replacement time for main rotor blades may also have application to tail rotor blades:

| Concept | Reference |
|---|---|
| In-Flight Rotor Tracking | Main Rotor Blade |
| Rotor Track Sensor System | Main Rotor Blade |

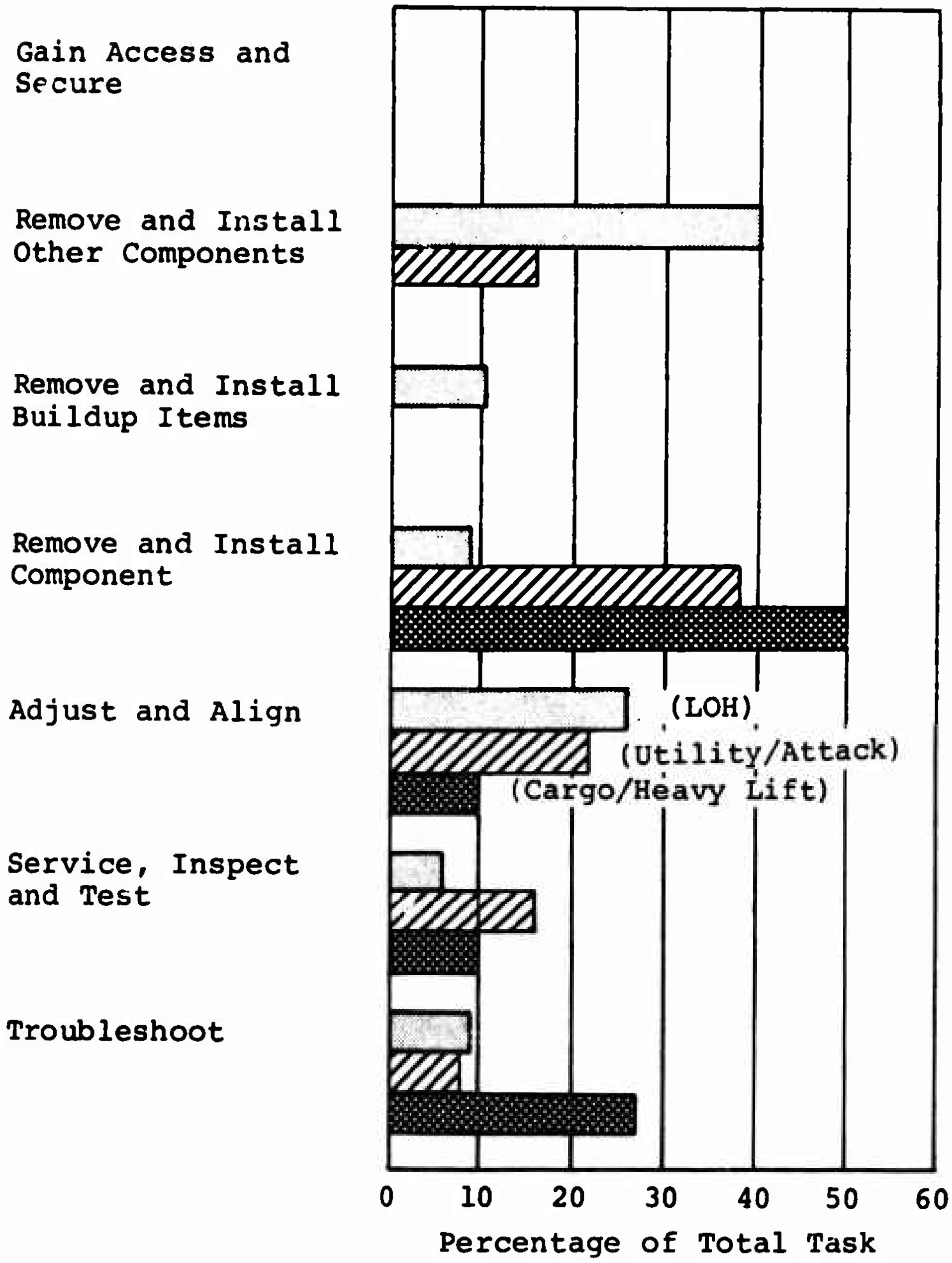


Figure 13. Component Replacement Time Distribution, Tail Rotor Blade.

# TAIL ROTOR HUB

## REPLACEMENT TIME FACTORS

The bar chart of Figure 14 shows that the major contributors to replacement time for tail rotor hubs in helicopters are removal and installation of other components, removal and installation of the hub itself, and post-installation rigging and adjustment.

### Shimming

On most helicopter models, the tail rotor flapping angle must be checked and adjusted following installation of a new hub. This is accomplished via shimming or the installation of selected spacers. In one series of helicopters, shimming is also required to obtain the proper pinch on the pitch change rod bearings.

### Rotor Tracking

Replacement of the tail rotor hub on most helicopter models requires tracking of the tail rotor and rigging of the tail rotor controls.

## STATE-OF-THE-ART SOLUTIONS

### Improved Shim Accessibility

The time required to adjust the blade flapping angle on teetering tail rotors might be reduced by keeping the tail rotor flapping control shims accessible in the stackup rather than burying them. Because fewer parts need to be removed to get at the shims, the chances of improper assembly would also be reduced.

### Increased Tail Rotor Disc Clearance

The time required to adjust the tail rotor blade flapping angle might be reduced by designing increased clearance between the tail rotor disc and the tail boom to avoid having to adjust the flapping stops. This would permit a larger tolerance on the blade flapping angle and the use of fixed stops. A slight weight increase might be incurred due to the increased length of the tail rotor gearbox output shaft, and there may be an aerodynamic penalty. The hub retention stackup could be simplified, however, thereby minimizing the possibility of incorrect buildup.

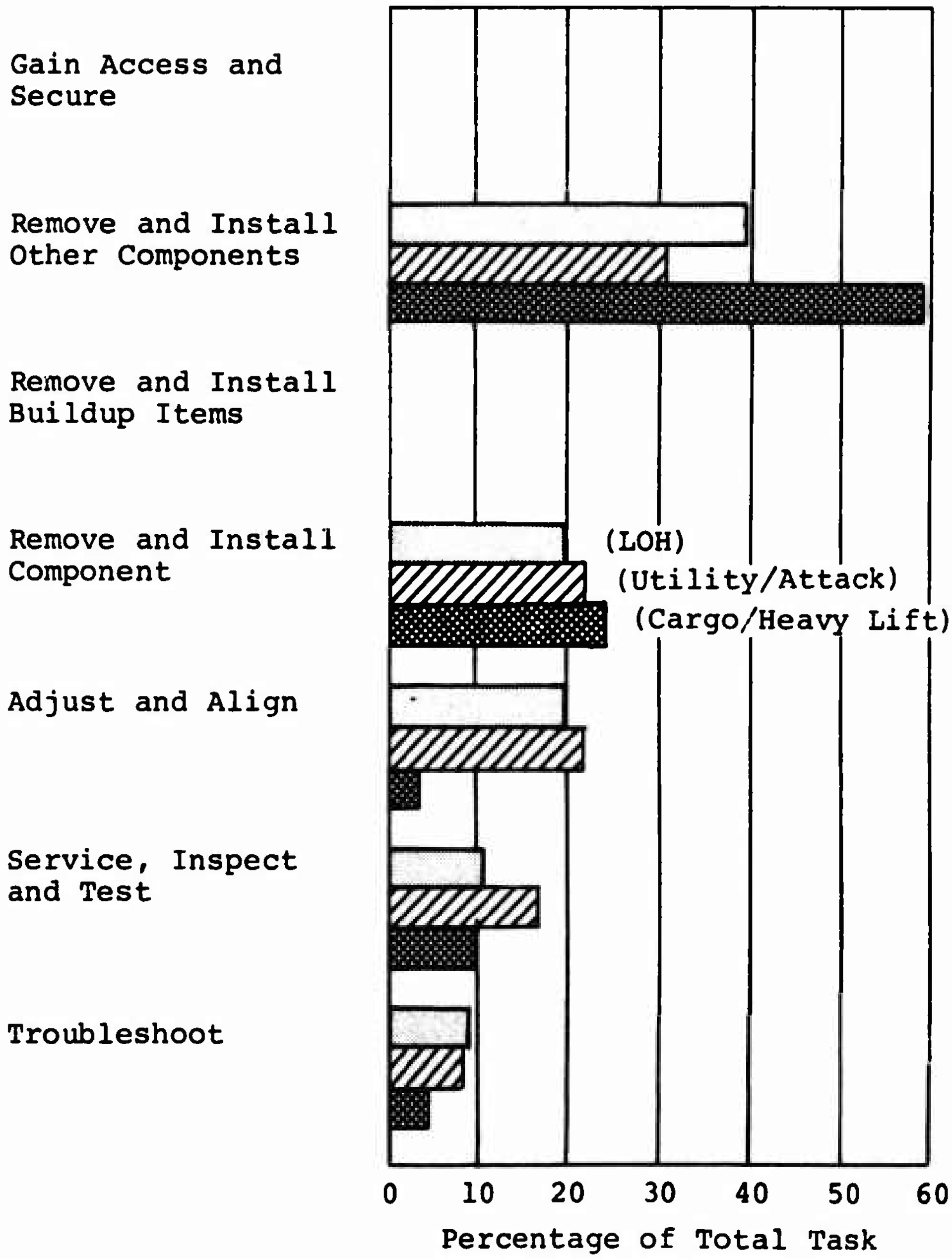


Figure 14. Component Replacement Time Distribution, Tail Rotor Hub.

## DESIGN CONCEPT CANDIDATES

Two installation design concepts proposed to reduce the replacement time for main rotor blades may also have application to the tail rotor hub:

| Concept | Reference |
| --- | --- |
| In-Flight Rotor Tracking | Main Rotor Blade |
| Rotor Track Sensor System | Main Rotor Blade |

# SWASHPLATE

## REPLACEMENT TIME FACTORS

The bar chart of Figure 15 shows that the major contributors to replacement time for helicopter swashplates are removal and installation of other components and removal and installation of the swashplate itself.

### Removal of Other Components

Replacement of the swashplate on all helicopter models requires removal and reinstallation of major components of the main rotor, including the rotor head and blades. Following reinstallation of these components, controls rigging and rotor tracking adjustments are often required.

### Handling of Small Parts

Removal and installation of the swashplate normally involve the handling of many small items of hardware which are subject to being lost or misplaced and are time-consuming to work with.

## STATE-OF-THE-ART SOLUTIONS

### Captive Attaching Hardware

The time involved in the removal, installation and handling of small items of hardware during replacement of the swashplate could be reduced by designing many of these items as captive hardware which would not be separated from the main assembly. There will be slight increases in the size, weight and cost of the swashplate.

### Swashplate Located Below Transmission

One approach to eliminating the need to remove the main rotor to replace the swashplate might be to locate the swashplate below the main transmission with the control rods passing upward through the rotor shaft and connecting to the rotor controls. The hydraulic actuators would have to be relocated and would probably be less accessible. Transmission replacement would be complicated somewhat because of the controls passing through the rotor shaft, but the installation might be designed such that the swashplate is only detached from the transmission rather than removed completely. The concept would require a through-shaft in the transmission and a lower shaft seal. The shaft rods would require guides in the rotor shaft and additional "walking beam" linkage in the rotor head.

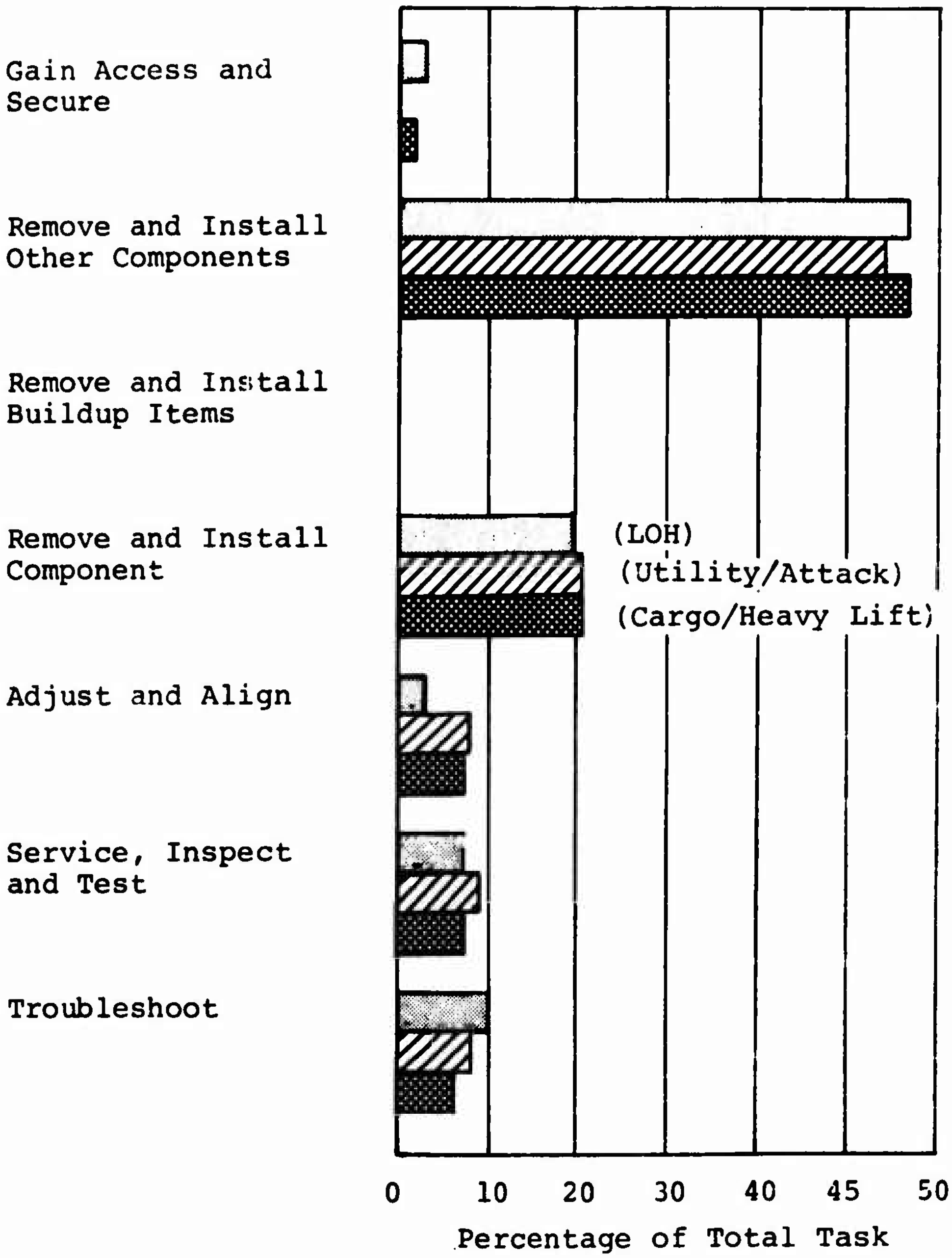


Figure 15. Component Replacement Time Distribution, Swashplate Assembly.

Although this concept is considered to be within the state of the art, a thorough study of such factors as control system kinematics, control loads, and stress levels would be needed to evaluate its feasibility.

## DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing swashplate replacement time in helicopters are two considered to be beyond the present state of the art as defined for this program. These concepts, described below, became candidates for the design study phase.

### Swashplate Located Above Rotor Head

The need to remove the main rotor to replace the swashplate might be eliminated by mounting the swashplate above the rotor head on a stationary shaft passing through the rotor shaft. The nonrotating lower controls would pass upward through the stationary shaft. The swashplate could be replaced without removing the rotor blades and hub, but replacement of the hub would be complicated by the need to remove the swashplate. Transmission replacement would also be penalized by the presence of the nonrotating controls passing through the rotor shaft. Hydraulic actuators would have to be relocated and may be less accessible. Total height of the helicopter would increase, possibly creating shipping and storage problems. Aerodynamic characteristics may be degraded. The high control loads on the shaft rods will require that the rods be heavily supported in the shaft, and substantial modifications to the lower control system would be necessary. Because of the many design problems and performance penalties inherent in this concept, the probability of developing a successful design is considered to be remote.

### Split Swashplate

Another approach to eliminating the need to remove and install the main rotor for replacement of the swashplate would be to split the swashplate into sections such that it could be assembled around the rotor shaft. This concept is one of the twelve design study projects described in the latter part of this report.

# HYDRAULIC FLIGHT CONTROL ACTUATORS

## REPLACEMENT TIME FACTORS

The bar chart of Figure 16 shows that the major contributors to replacement time for hydraulic flight control actuators in helicopters are removal and installation of the actuator itself and post-installation servicing.

### Inaccessibility of Hydraulic Line Connectors

Several hydraulic lines attach to the typical actuator. These lines are usually difficult to disconnect due to their proximity to each other and to structure and other components.

### Oil Dripping From Disconnected Lines

Once disconnected from the actuator, the several hydraulic lines drip oil which is time-consuming to clean up.

### Restricted Working Space

Once disconnected from the control actuator, the typical hydraulic line must be moved to provide clearance. Space to maneuver the lines is frequently so restricted that permanent twisting or kinking of the lines sometimes occurs.

### Cross-Connection of Lines

When reconnecting the several hydraulic lines to the typical actuator, cross-connection is often possible. This condition may not be discovered until the maintenance operational check.

### Adjustment of Cylinder Length

On some helicopter models, replacement cylinders are not supplied with a preset length and must be adjusted to match the length of the removed cylinder.

### Improper Interchange of Cylinders

In one helicopter model, three cylinders are used which appear identical and can physically be interchanged, but which are not functionally interchangeable. Improper installation sometimes occurs.

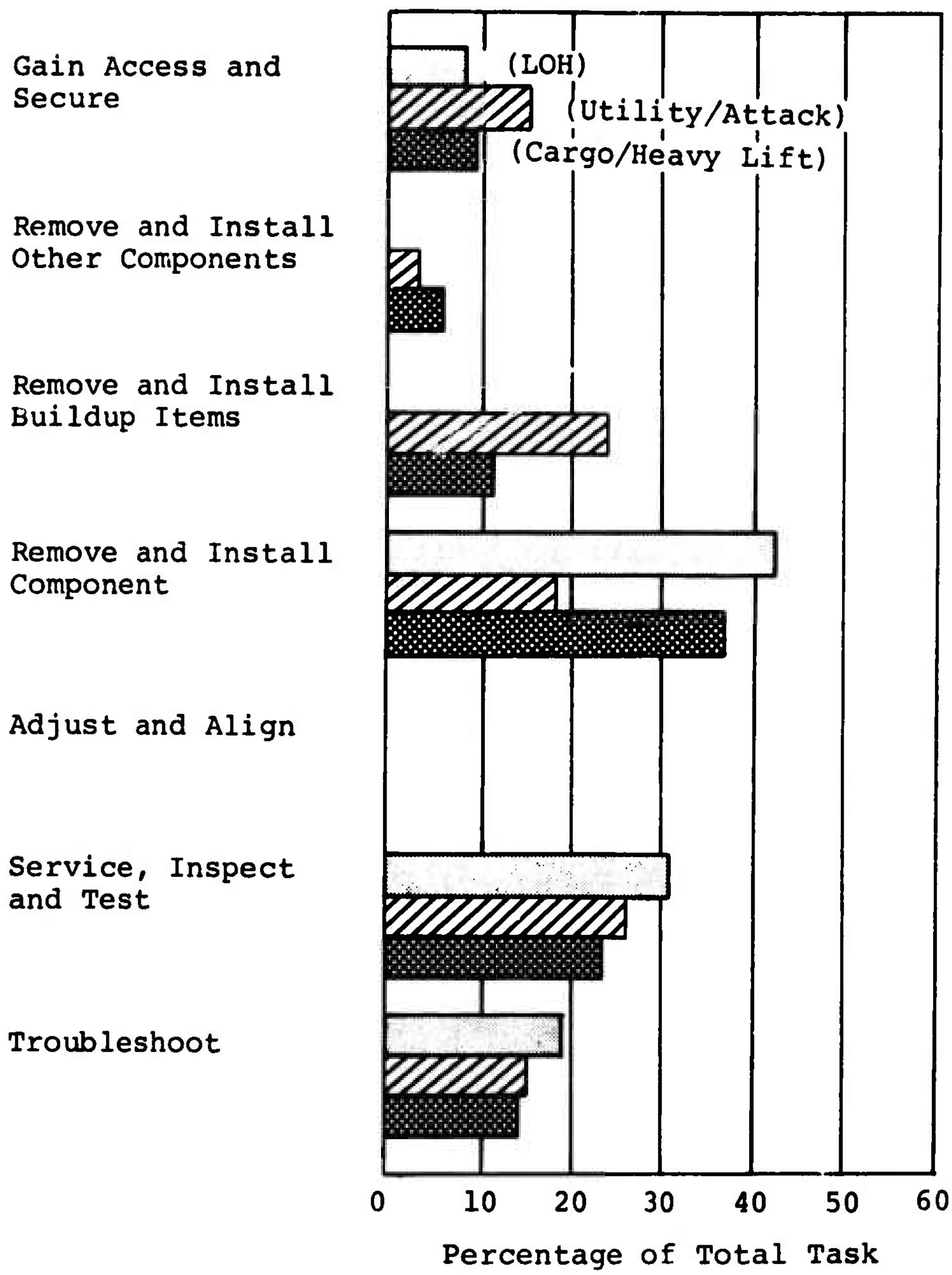


Figure 16. Component Replacement Time Distribution, Hydraulic Flight Control Actuators.

## Custom Shimming

In some installations, the hydraulic flight control actuator must be custom shimmed to compensate for tolerance variations between the clevis fittings and cylinder rod ends.

# STATE-OF-THE-ART SOLUTIONS

## Split Manifold Connectors

One approach to easing the removal and installation of hydraulic flight control actuators would be to provide a split manifold connector for each actuator location. All actuator lines would pass through the manifold, one half of which is part of the actuator and the other half of which is part of the aircraft installation. Disconnection would be effected by release of a single fastener. That half of the manifold connector which is fixed to the airframe would be located behind or to one side of the actuator, thereby allowing unimpeded access for its removal. Cross connection of lines would be impossible. The split manifold connector would be heavier and more costly than existing connectors, however. Arrangement of fluid ports on the actuator and the associated passages within the actuator to provide a compact hydraulic interface area may be difficult to achieve. The probability of developing a technically feasible design is considered to be high, however.

## Fixed Actuator and Valve Body

Another approach to reducing the replacement time for hydraulic flight control actuators would be to provide a fixed actuator and valve body with a plumbing manifold which would allow lines to be fixed to structure. The actuator mounting plane would comprise the hydraulic interface. This concept would eliminate flexing of lines during helicopter operations, thus improving their reliability. It would also allow modularization of the actuator, with individual modules bolted to the outboard side of a plate which is fixed to the airframe. To take full advantage of this concept, the actuators would have to be located where they need not be disturbed to replace other components such as the main transmission. Normally, lines would not be disconnected and the possibility of cross-connection would be eliminated. Weight of the new actuator would likely be greater than current design, however. Although considerable effort would be required in the design of the actuator, plumbing and structural installation to achieve the desired harmonious arrangement, the probability of developing a successful design is considered to be high.

## Disconnects With Automatic Shutoffs

The time consumed in removing and installing hydraulic line connections to the actuator could be reduced through the use of hydraulic quick-disconnects with automatic shutoffs. The disconnects would eliminate the need for wrenches and would thus allow the actuators to be installed more easily in confined areas. Incorporation of shutoff valves would add to the complexity and weight of the actuator, however. Design considerations would include such objectives as minimum size, low pressure drop, low actuation forces and reliability of operation. The probability of developing a successful design is considered to be high.

## Increased Cylinder Overtravel

The problems associated with adjusting the hydraulic actuators to a prescribed length upon installation might be avoided by providing sufficient overtravel that close matching of cylinder-to-control travel is not required. This would eliminate the need to mechanically adjust the length of the cylinder prior to installation. The possibility of faulty adjustment would be eliminated. The interchangeability of actuators in slightly different installations would be enhanced. There would be a slight weight penalty. Incorporating this concept would require a comprehensive study of installation tolerances and the ability to provide control system stops elsewhere in the control system. The probability of developing a successful design is considered to be high.

## Fixed-Length Cylinders

Another approach to the problem of mechanically adjusting the length of hydraulic cylinders upon installation would be to fabricate all cylinders to a repeatable dimension and then to rig each control system to accept this fixed length. The possibility of faulty adjustment would be eliminated, and there could be a small weight savings. The commonality of cylinders for slightly different installations is sacrificed, however. Incorporating this concept requires that good overall tolerance control be part of the actuator design either by closely controlling finished part dimensions or through sizing procedures at assembly. The probability of developing a technically feasible design is considered to be high.

## Noninterchangeable Mounting Provisions

The inadvertent interchange of actuators during installation could be avoided by designing the mounting provisions so that each actuator could be mounted only in its proper location. This could be effected with lugs, dowels, etc. A slight weight penalty would be involved.

## Slip-Fit Bushings at Actuator Clevis

The need to custom shim actuators in some installations might be eliminated through the use of slip-fit bushings on one side of the actuator clevis. Eliminating the need to stock shims will simplify logistics somewhat, and the slip-fit bushings could be restrained to eliminate loss. A study of installation tolerances would be needed to incorporate this concept.

## Flexible Actuator Clevis

The need to custom shim actuators in some installations might be eliminated by making the actuator clevis sufficiently flexible to accommodate tolerance variations in the width of the rod ends. Eliminating the need to stock shims will simplify logistics somewhat. A study of the required deflection and stress levels would be needed to evaluate the feasibility of this concept.

# DESIGN CONCEPT CANDIDATES

Among the installation design concepts proposed for reducing hydraulic flight control actuator replacement time in helicopters were those considered to be beyond the present state of the art as defined for this program. These concepts, described below, became candidates for the design study phase.

## Quick Disconnect With Automatic Shutoff

The time involved in servicing hydraulic flight control actuators and cleaning up spilled hydraulic fluid after installation might be overcome through design of an easily manipulated quick disconnect with automatic shutoff and a positive locking mechanism. The fitting might be, for example, a straight plug-in type with a side-locking pin arrangement. The quick disconnect would eliminate the dripping and subsequent cleanup of spilled hydraulic fluid and might eliminate the need to service and bleed the system after replacement of an actuator. There would likely be a small weight penalty and an increase in cost. Some of the design problems would include providing good protection for the seal member and a method of manipulation that is easily understood, foolproof and demanding of little force. Sufficient access would be needed for operation of the disconnects. This concept would require a substantial design study effort and is considered to have only a moderate probability of being successfully implemented.

## More Flexible and Durable Hose

The problems associated with the twisting and kinking of hydraulic hoses during removal and installation of flight control actuators might be alleviated through the design of hydraulic hose of more flexible and durable construction. The absence of such hose on the market indicates, however, that the required materials and manufacturing technology are presently unavailable.

## Hydraulic Hinge Joint

The problems associated with the twisting and kinking of hydraulic hoses during removal and installation of flight control actuators might be alleviated through design of a hydraulic hinge joint which could accommodate manifold motion without the need for large hose loops. Lines could be readily moved out of the way without twisting. The concept might involve small penalties in weight, cost and reliability. A research effort would be needed to investigate the feasibility of a hydraulic joint of this type.

## Mixed Disconnects

The problems associated with cross-connecting hydraulic lines during installation of flight control actuators might be eliminated by mixing male and female disconnects to preclude improper connection. Hoses with male fittings are not stock items and would have to be specially provisioned, however. Some confusion might develop on the part of the mechanic in determining whether to restrain the fitting in the cylinder housing or the metal grip on the hose while breaking the torque on the "B" nut. The concept would be limited to pairs of lines and, although technically feasible, may be impractical from a logistics standpoint.

## Keyed Quick Disconnects

The problems associated with the cross-connection of hydraulic lines during installation of flight actuators might be prevented through the use of differently keyed quick-disconnect fittings. This concept is one of the twelve design study projects described in the latter part of this report.

# STARTER GENERATOR

## REPLACEMENT TIME FACTORS

The bar chart of Figure 17 shows that the major contributors to replacement time for starter generators are tasks associated with removal and installation of the component itself.

### Mounting Stud Inaccessibility

On some models, the starter generator is mounted on the engine with six or eight nuts secured to studs. Some of the nuts are difficult to get at, and cumbersome "crow's foot" wrenches are frequently required.

### Separately Connected Electrical Leads

On some models, several electrical leads must be disconnected when replacing the generator. These usually have to be tagged to insure that they are replaced on the proper terminals and taped while disconnected.

## STATE-OF-THE-ART SOLUTIONS

### Multiwire Connector

The time involved in removing, taping, tagging and reinstalling several electrical wires when replacing the starter generator could be eliminated substantially by incorporating a single MIL-C-5015 electrical connector. The connector, which requires only hand tightening and safety wire, would replace the several connections now made. No tools would be required and the chance of cross-connection would be eliminated. The disconnected wire ends are electrically insulated, which avoids the taping task. These connectors, which are presently available in sizes large enough to handle starter currents, will be bulkier and heavier, however, than the individual wires they would replace.

### Related State-of-the-Art Solutions

Two state-of-the-art concepts having a potentially beneficial effect on the replacement time for starter generators are covered elsewhere in this report.

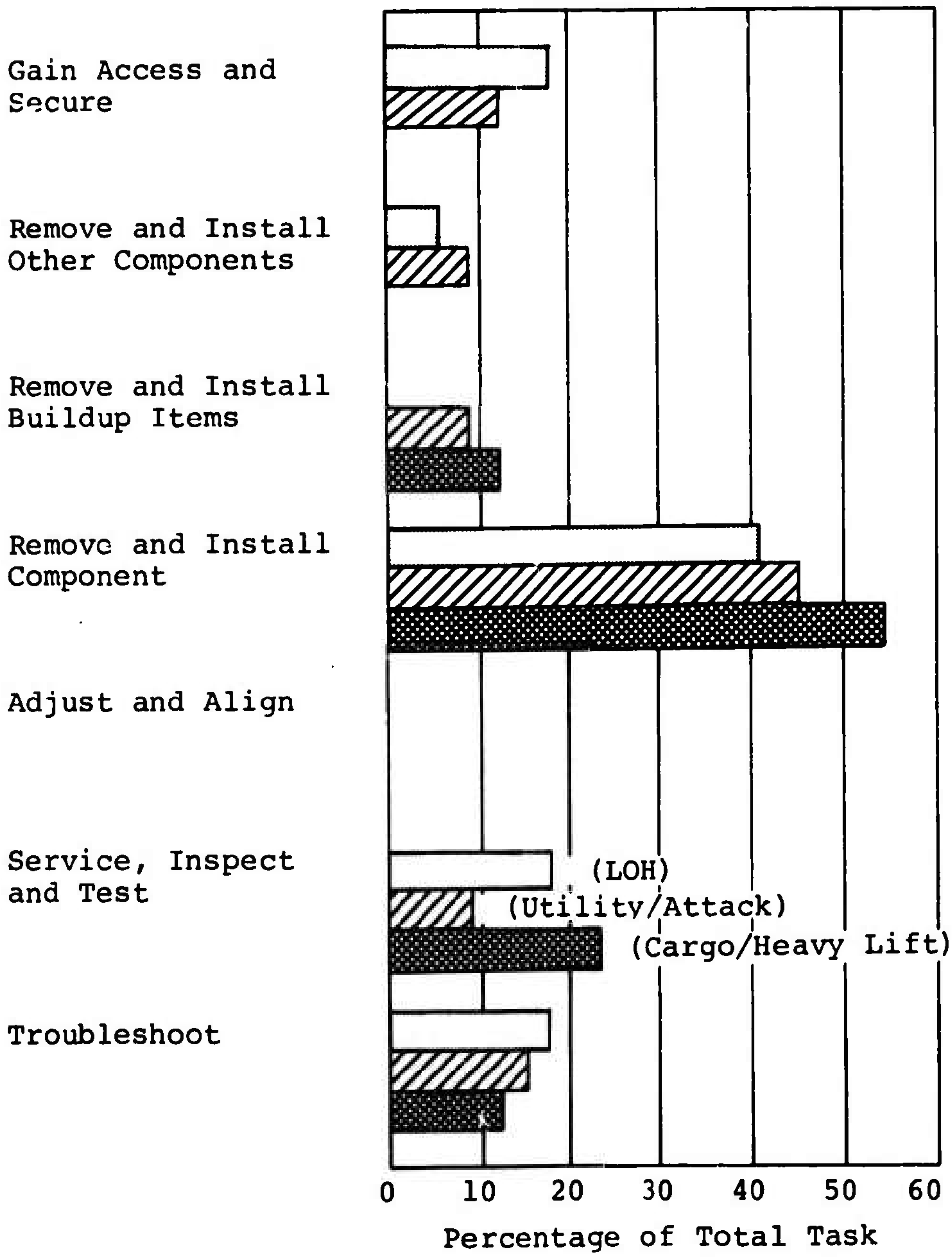


Figure 17. Component Replacement Time Distribution, Starter Generator.

These concepts and the generic components under which they are found are:

| Concept | Reference |
| --- | --- |
| Fuel Control Attaching Nuts | Fuel Control |
| "V" Band Attachment of Accessories | Engine |

## PHASE II GUIDELINES AND METHODS

### ADVANCE TECHNOLOGY DESIGN CONCEPTS

The design study work conducted in Phase II represents the major effort of the program. Twelve independent design projects were conducted, among which are represented concepts of widely varying scope and complexity.

One of the twelve concepts involves, for example, a simple and inexpensive method of keying hydraulic disconnects to prevent improper installation. Its simplicity makes it the least ambitious of the twelve projects undertaken but, correspondingly, the one with least risk from the standpoint of future development. Toward the opposite end of the spectrum are projects such as a modularized main transmission. This represents a vastly more far-reaching concept and one which consequently bears considerable development risk. Between these two extremes are found concepts of varying magnitude and complexity.

The extent to which each concept could be developed corresponds to the level of innovation and design involvement it represents. The simpler concepts, such as the keyed hydraulic disconnects, have been developed rather fully since, in this case, concept and final design are nearly synonymous. For more involved concepts, the modularized main transmission, for example, it was not possible to progress beyond the purely conceptual stage. Here, a very substantial engineering effort separates concept from final design. Sufficient design definition was attained, however, to permit at least a gross engineering appraisal of each concept's potential merit.

#### Design Study Method

The design study projects all followed a similar pattern of development, beginning with the suggestion of various technical approaches. Maintainability and design personnel evaluated the alternatives and selected the one concept which appeared to offer most promise. The selected concept was then developed more completely, involving, in most cases, several design iterations leading to a final selection. In the final design step, finished artwork was prepared showing the key features of the concept. Engineering notes were prepared to accompany the artwork.

All of the major dynamic systems of the helicopter - drives, rotors, powerplant, controls and hydraulics - were represented in one or more of the design projects. The basic concepts

came from experienced design people in these areas. As the concepts were later being developed, various engineering support groups such as stress, weights and aerodynamics were consulted as questions or problems arose. Since the work was not to progress beyond a conceptual phase, however, these supporting disciplines were not required to be as intimately involved in the design process as they would in a more formalized effort.

## Design Review

At the outset of the program, it was recognized that substantial improvements in helicopter maintainability could not be brought about without penalty. Improving maintenance would, in most instances, work to the detriment of other factors such as cost or weight. In order to identify these factors, Kaman engineering support groups reviewed the twelve final concepts and commented upon each from the standpoint of their special area of interest. This final engineering review was undertaken to identify the positive and negative implications of each concept as they relate to maintenance, reliability, stress, aerodynamics, weight and cost.

Being of conceptual nature, the designs did not, for the most part, lend themselves to quantitative analysis, and so the review was mainly of qualitative character. The critical aspect of the review was stressed to avoid any tendency to emphasize positive factors and play down negative ones, i.e., to supply blanket endorsements. For the simpler concepts, sufficient information was available to make rather definite judgements. Concepts less well defined were evaluated in more tenuous terms. Very often, the opinions expressed by Stress, Weights, etc., were based on assumptions regarding the detailed characteristics that a final design might possess or various options that might be considered.

## Estimates of Development Potential

One final task assigned by the Army was to estimate, for each of the proposed design concepts:

1. Improvement potential.

2. The probability that an acceptable solution can be developed.

3. The estimated cost (in time and money) of developing the improvement.

Estimating improvement potential presented some difficulty.

The benefit that might be realized from a given design concept is contingent upon many factors in addition to the discrete number of man-hours that are saved at each replacement of the component. Among these are the replacement frequency (a function of component reliability), the size of the aircraft fleet, and its utilization. Also involved are such intangibles as the effect on aircraft payload and performance and any secondary impact, positive or negative, on other systems or installations. All of these factors must be related to a future aircraft of yet unknown design. For these reasons, it was impractical to attempt to arrive at any numerical estimate of improvement potential. Instead, the estimate was made to reflect the combined judgement of experienced design and maintainability personnel of each concept's potential worth in relation to its expected development cost. A "high" potential improvement rating means, therefore, that the development of a concept would probably effect a favorable payoff. A "low" rating, conversely, reflects the opinion that the return would probably not justify the required investment.

Estimating development costs (and time) also presented some difficulty. Some of the concepts studied would be economically worthwhile undertakings only as part of a larger aircraft design effort. To develop a new main rotor design for the purpose of incorporating a simplified blade attachment scheme would be unrealistic. To estimate that part of the total design and development cost which the blade attachment would represent, should a new rotor be developed, is equally unrealistic. In these cases, and those where the required development effort is too involved to assess at this time, no estimates have been made. For the majority of the twelve design concepts, however, development cost estimates have been made.

## Documentation of Phase II Results

Results of the Phase II advance technology design concept study are documented in twelve individual sections, one devoted to each concept. Each section includes a discussion of the various approaches considered, a description of the final design concept, and an evaluation of its expected benefits and penalties. Estimates of development potential and cost are also presented. For one concept, the split drive shaft hanger bearing, a discussion of the several design iterations leading to selection of a final candidate is presented. This is done to show the typical evolution of a concept in the design project studies.

## MODULARIZED MAIN TRANSMISSION

The objective of this design study was to develop a concept for rapid replacement of a main transmission without having to remove or disturb the main rotor or the rotor controls. A constraint placed on the concept was that the transmission driven accessories be mounted on a separate drive module so that they too would remain undisturbed during a transmission change. Emphasis was placed also on minimizing the use of special ground support equipment.

### APPROACHES CONSIDERED

Two basic approaches were investigated:

1. A transmission located below the cabin roof with lateral rails under stub wings passing into the cabin. A separate rotor mast assembly and accessory drive gearbox would be provided.

2. A transmission located above the cabin roof with longitudinal rails on the roof and a separate rotor mast assembly and accessory drive gearbox.

#### Transmission Below Cabin Roof

The first concept evolved around a transmission located in the aft cabin and mounted to a support/manifold assembly at the roof line. Above the roof, mounted to the top side of the support manifold, is a rotor mast assembly which is capable of supporting the main rotor and its controls when the transmission is not installed.

Also mounted to the top side of the support/manifold are all accessories driven by the transmission and all lube lines normally attached to the transmission. The support/manifold is permanently fixed to aircraft structure. It contains no bearings, gears, seals, etc., which are subject to wear or which need to be removed for overhaul. All accessory input shafts are sufficiently long to allow them to pass through the support/manifold and be driven directly by the transmission output shafts. These shafts automatically engage as a replacement transmission is drawn up into contact with the support/manifold. As transmission-to-support/manifold engagement occurs, so does mating of the fluid manifold halves.

Dual rails under a stub wing above the cargo door facilitate the task of conveying the transmission from the trailer to the support/manifold. Conventional block and tackle devices,

hung from rollers engaged in the rails, are used to raise and lower the transmission.

Analysis of this concept revealed no insurmountable problems from a technical standpoint. However, the concept did have obvious limitations with respect to future applications. The most significant of these was its nonsuitability to a twin-engine helicopter configuration. Another possible drawback was the need for stub wings in line with the transmission which would probably place them above the cabin doors. Use of the wings for other purposes, such as external stores carriage, would thus be severely restricted.

## SELECTED CONCEPT - MODULARIZED MAIN TRANSMISSION ON RAILS ABOVE CABIN ROOF

Figures 18 and 19 depict a concept for modularizing a main transmission by creating three individually replaceable subassemblies. As shown, the concept is applied to a twin-engine helicopter, but it could be applied equally well to a single-engine configuration with the engine placed on the fuselage roof behind the transmission.

Essential to the concept is a shelf of hard structure permanently attached to the fuselage. To the top side of the shelf is bolted the rotor shaft module which supports the main rotor. To the forward side is bolted an accessory drive gearbox on which all accessories are mounted. The forward side of the hard structure is arch-shaped to allow passage of the main module which slides on longitudinal rails fixed to the cabin roof. Teflon pads on the transmission minimize sliding friction.

A main module is installed by hoisting it above the roof rails forward of the accessory drive gearbox. From this position, the transmission may be lowered between two blades of a four-bladed rotor without folding the blades. The module is next pushed aft until contact is made with positive stops. Several transmission support bolts pass through the rotor shaft housing and engage the main module. As the bolts are tightened, the transmission is drawn up into engagement with the rotor shaft housing. A female pilot in the rotor shaft housing and a mating male pilot on the transmission housing ensure concentricity. Torque is transmitted to the rotor shaft through a face-type spline. The spline halves are locked together by a draw bar which passes down through the rotor shaft and engages an internal thread in the planet gear carrier. This mechanism is shown in its engaged and disengaged positions in Figure 20.

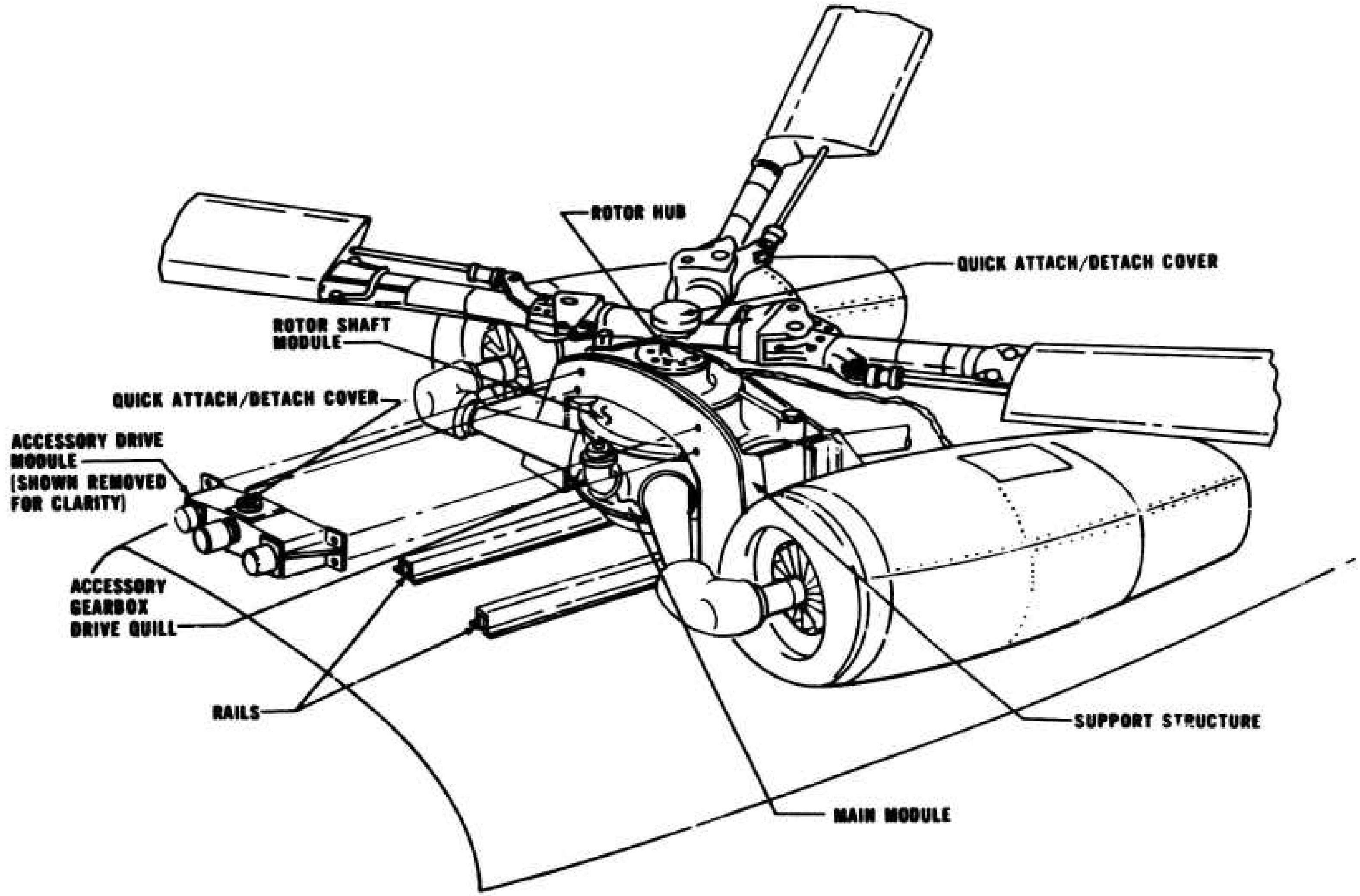


Figure 18. Modularized Main Transmission, Showing Accessory Drive Module Being Removed.

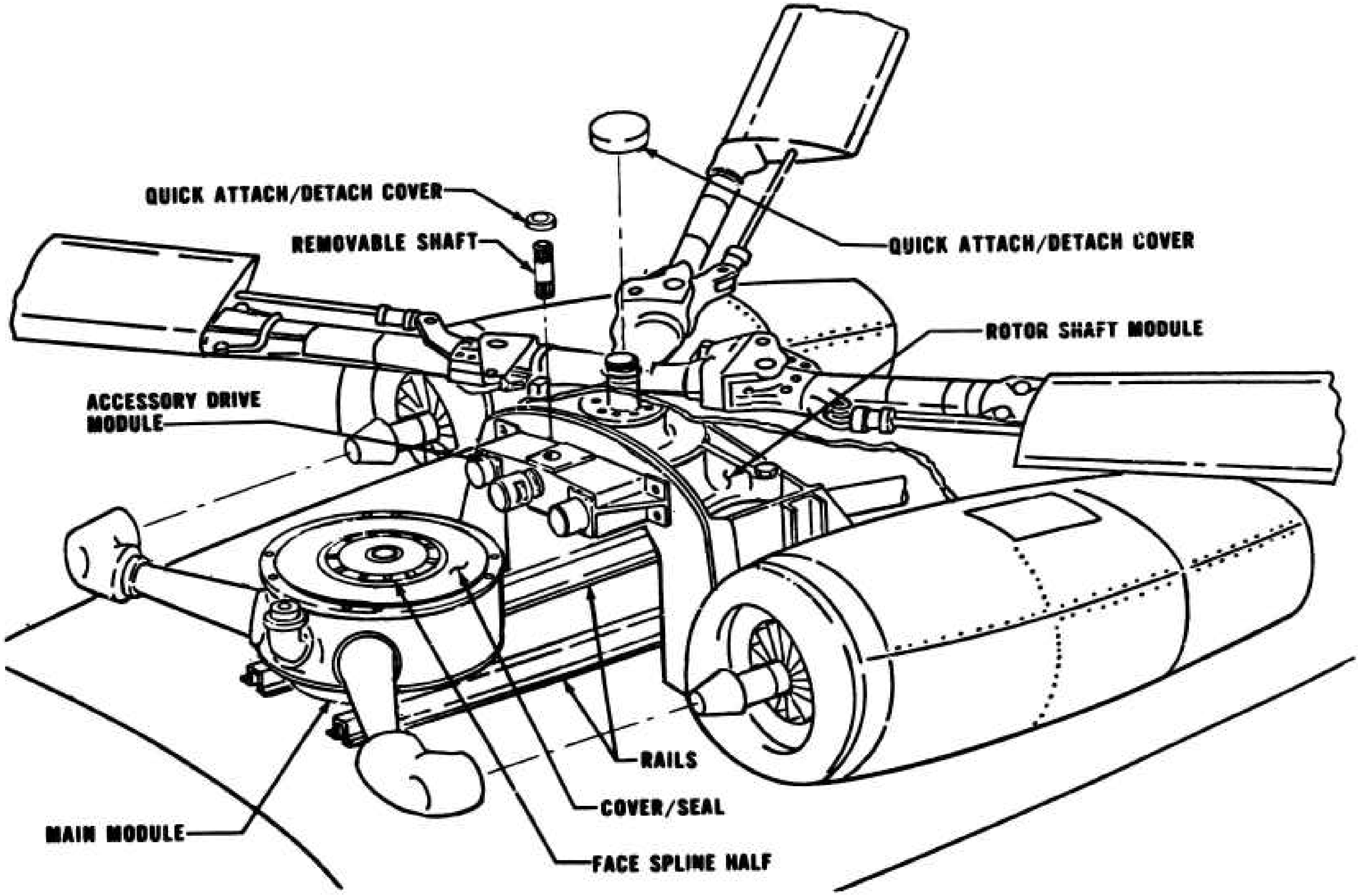


Figure 19. Modularized Main Transmission, Showing Main Module Being Removed.

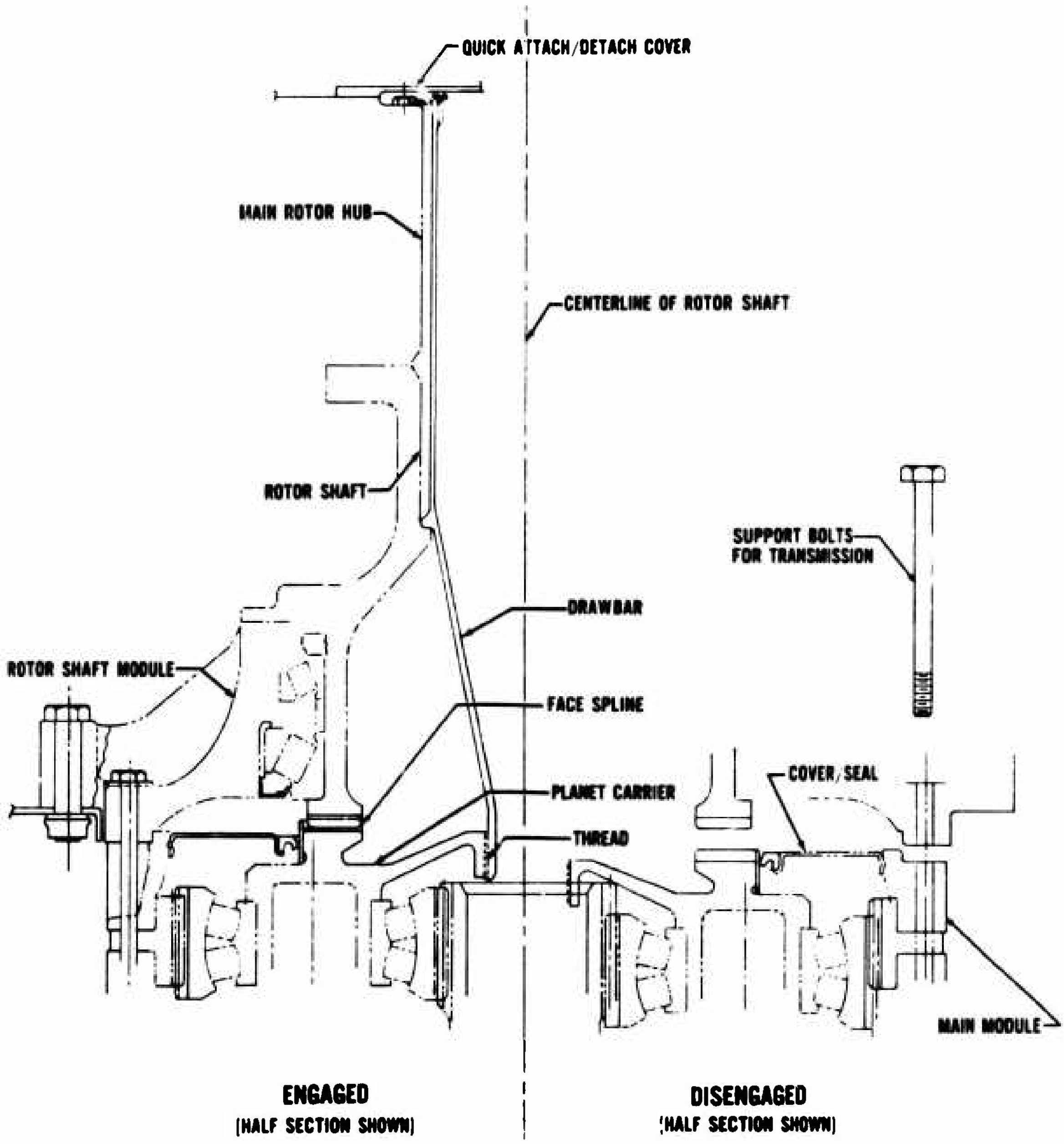


Figure 20. Sectional View Through Rotor Shaft of Modularized Main Transmission.

An accessory drive gearbox is installed by bolting it to the forward side of the shelf support arch as shown in Figure 18. The mounting surfaces are precision machined and keyed to ensure proper alignment of the drive quill in the main module with the input quill in the accessory drive gearbox. A splined connector shaft transmits torque from one quill to the other. The shaft is easily removed through a quick attach/detach cover on the top side of the accessory gearbox. A sectional view through the main module-to-accessory drive module connector shaft is shown in Figure 21. Of the three modules created in this concept, only the rotor shaft module requires prior removal of the main rotor and its controls when replacement is necessary. The rotor shaft module, however, is by far the least complex mechanism of the three and presumably will be the most reliable (longest mean time between removals).

## Benefits

As originally intended, the principal benefits derived from the proposed concept occur as component replacement time improvements.

### Maintenance

The main module, which is the most complex of the three and presumably will have the highest failure rate, is designed to be the easiest to replace. It is necessary to disturb neither the main rotor, the rotor controls nor any of the accessories. The main module may be hoisted or lowered through the space between rotor blades even with a four-bladed main rotor. Having the transmission in three modules also means that only a portion of the entire assembly need be replaced due to any given failure.

The rail area in front of the main module is clear of any obstructions to allow free passage of the main module. This has the added advantage of providing excellent access to accessories mounted on the accessory drive module.

### Reliability

The main rotor blades and main rotor hub will be removed from the aircraft with less frequency if the proposed concept is adopted. This should have a positive effect on the aircraft's overall reliability due to fewer incidents of maintenance-induced damage.

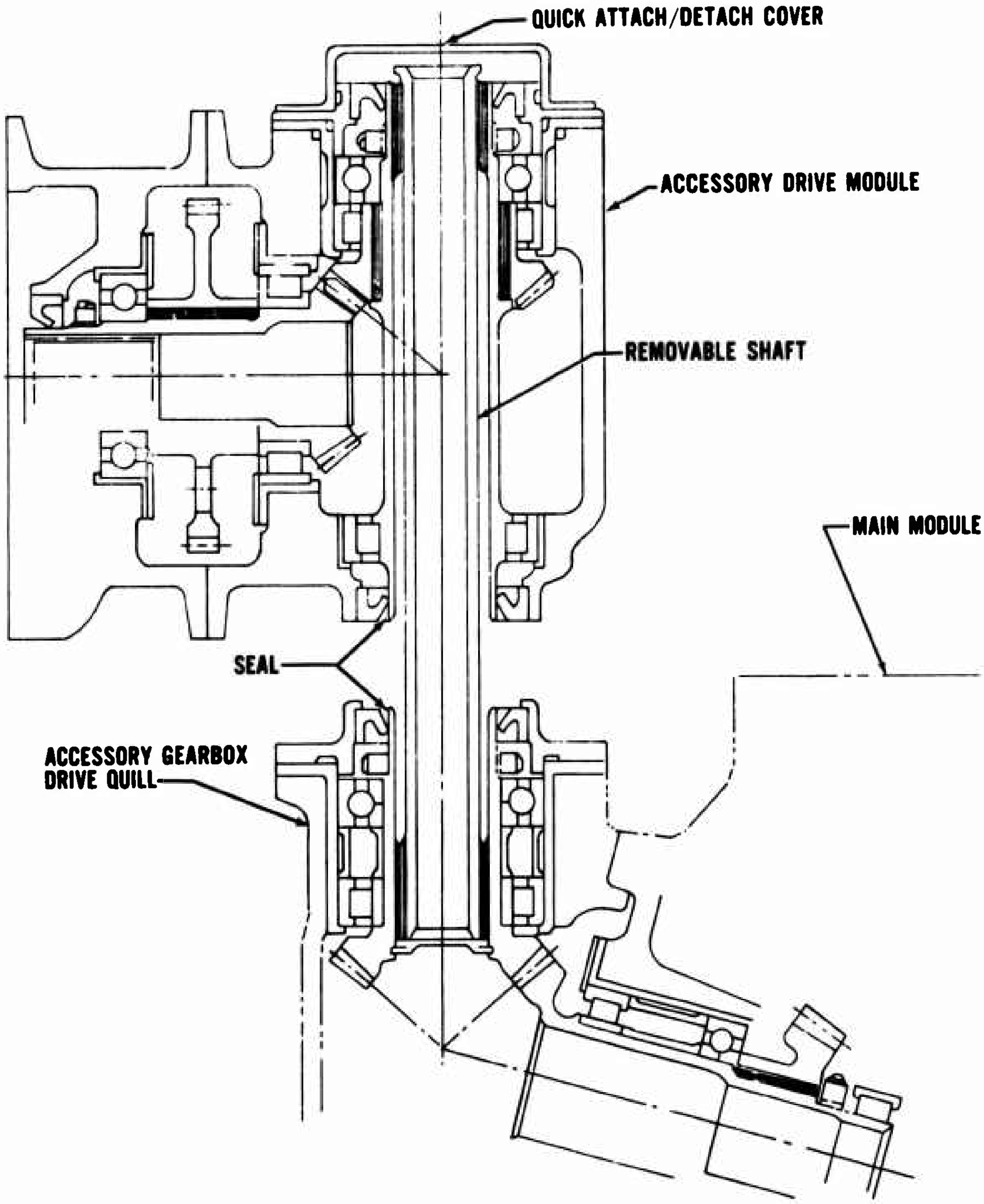


Figure 21. Sectional View Through Accessory Gearbox Drive Shaft of Modularized Main Transmission.

## Penalties

Most penalties listed here are the type which can be minimized, if not entirely eliminated, during a design development program.

### Maintenance

During installation of the main module, there is no way to determine if the mating halves of the face spline are engaged prior to tightening the draw bar which passes down through the rotor shaft and engages a thread in the planet gear carrier. Also, a special tool will be required to accommodate the high torque requirements of the draw bar. The transmission support bolts which draw the main module up into engagement with the rotor shaft module must be sequentially tightened (or loosened) with small turn increments; otherwise, the mating pilots will bind. Replacement of the rotor shaft module still requires prior removal of the main rotor. This module, however, presumably has the highest reliability of the three.

### Reliability

The lower spline of the connector shaft for the accessory drive gearbox module is not sealed. A problem with corrosion may result.

### Stress

The face spline pressure angle resists engagement and, due to a relatively nonrigid connection in this case, is susceptible to fretting and destructive loosening. The accessory drive gearbox is conventional, but no lubrication is provided for its connector shaft. The shelf structure which supports the transmission modules is the most highly loaded and most critical of the entire airframe. A good deal of consideration will need to be given to this structure in the design stage to ensure proper static and fatigue strength.

### Weight

An increase of 5 to 10 percent of the conventional transmission weight should be anticipated.

### Cost

An estimated increase in cost of up to $15,000 per aircraft could result from modularizing the transmission.

## Estimated Development Cost

Time - A program to develop a modularized transmission can best be conducted by a prime helicopter manufacturer. It is estimated that a program carried through to the flight test stage would require 90,000 to 100,000 man-hours over a 4-year period.

Dollars - Such a program would cost approximately 2 million dollars.

Success Probability - Moderate to high.

## Estimated Improvement Potential

The very substantial development cost, coupled with a very high anticipated recurring cost, makes this concept economically unattractive in its present form. If a way could be found to fully modularize the transmission so that all segments were replaceable individually and as an entire assembly, including that portion presently represented by the rotor mast module, the concept might become more favorable.

## QUICKLY REMOVABLE TAIL ROTOR GEARBOX

The objective of this study was to develop a concept for rapid replacement of a tail rotor gearbox without the need for prior removal of the tail rotor or its controls. One feature sought was the capability to stow the tail rotor while the gearbox was not installed. Other constraints imposed were minimal reliance on special tools and the exclusion of any mechanism which required custom fitting such as shimming.

### APPROACHES CONSIDERED

This design study produced two different approaches to the concept of a quickly removable tail rotor gearbox:

1. Gearbox split into two individually replaceable modules with the outboard module supporting the rotor.

2. Output shaft split into two sections, the outboard section being a collective swashplate assembly which supports the tail rotor when the gearbox is removed.

### Gearbox Split Into Two Modules

In this concept, a conventional gearbox is split into two modules, each mounted on opposite sides of a support bracket on the tail boom. The inboard module is the most complex mechanism, containing all the gearing and an integral oil lube system. The outboard module contains only shaft bearings which are permanently lubricated. Both modules require periodic overhaul, but the outboard one, due to its simplicity and presumed high reliability, should enjoy a long mean-time-between-removals.

Replacement of the inboard module requires only that the flex coupling at the input shaft be disconnected and that three mounting bolts be removed. Replacement of the outboard module requires prior removal of the tail rotor and its controls but does not require removal of the inboard module.

This design involved great weight and cost penalties in exchange for only partially satisfying the original design goals. Essentially, only a section of the conventional gearbox was replaceable without disturbing the rotor. Little improvement in gearbox overall replacement time was anticipated. The design therefore was not considered worthy of further development.

## SELECTED CONCEPT - TAIL ROTOR GEARBOX WITH TWO-PIECE OUTPUT SHAFT

Figures 22 and 23 depict the tail rotor gearbox concept judged to offer the best potential improvement in replacement time. The gearbox used in this concept is conventional except that its output shaft is split into two sections, joined together via bolted flanges.

On the outboard section is located a collective swashplate which functions in the normal manner during rotor operation, but which performs the additional task of supporting the rotor when the gearbox is not installed. Figure 22 shows the installation ready for normal operation. Figure 23 shows the gearbox removed and the swashplate supporting the tail rotor. Two ball-lock pins secure the outboard shaft section to the gearbox mount fitting to prevent movement due to wind forces.

### Benefits

A significant reduction in the time required to replace a tail rotor gearbox is the major improvement afforded by this concept.

#### Maintenance

The tail rotor gearbox may be replaced without first removing the tail rotor or even disconnecting the tail rotor controls. The outboard end of the gearbox output shaft becomes a detail of the swashplate assembly and assumes the same TBO or replacement time.

#### Reliability

There will be fewer removals of the tail rotor and the swashplate. This should result in less frequent occurrences of maintenance-induced damage.

### Penalties

The most important penalties appear to be increased cost and weight.

#### Maintenance

The two ball-lock pins used to stow the tail rotor become loose items when the tail rotor gearbox is installed.

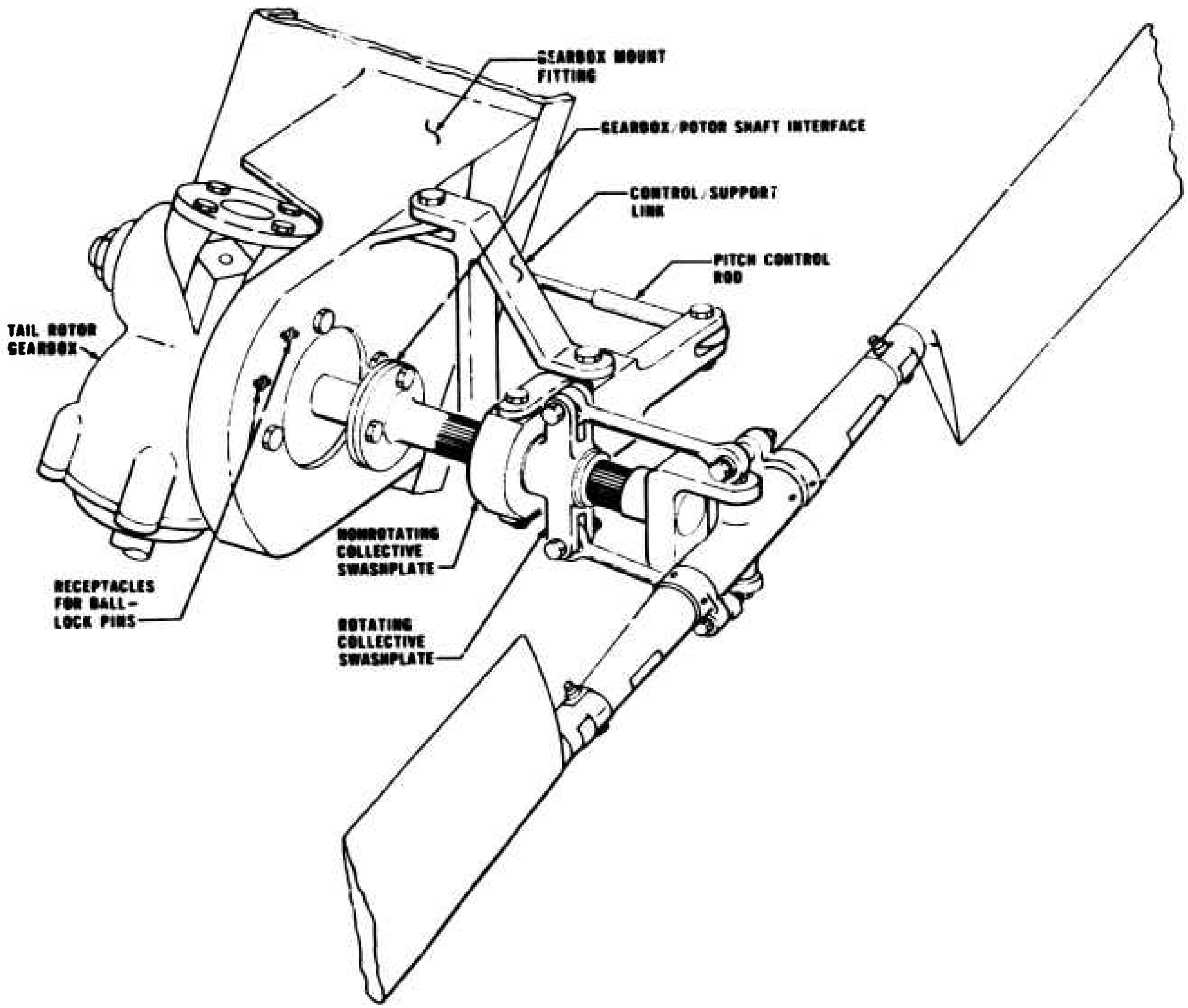


Figure 22. Tail Rotor Gearbox With Sectionalized Output Shaft and Stowable Tail Rotor.

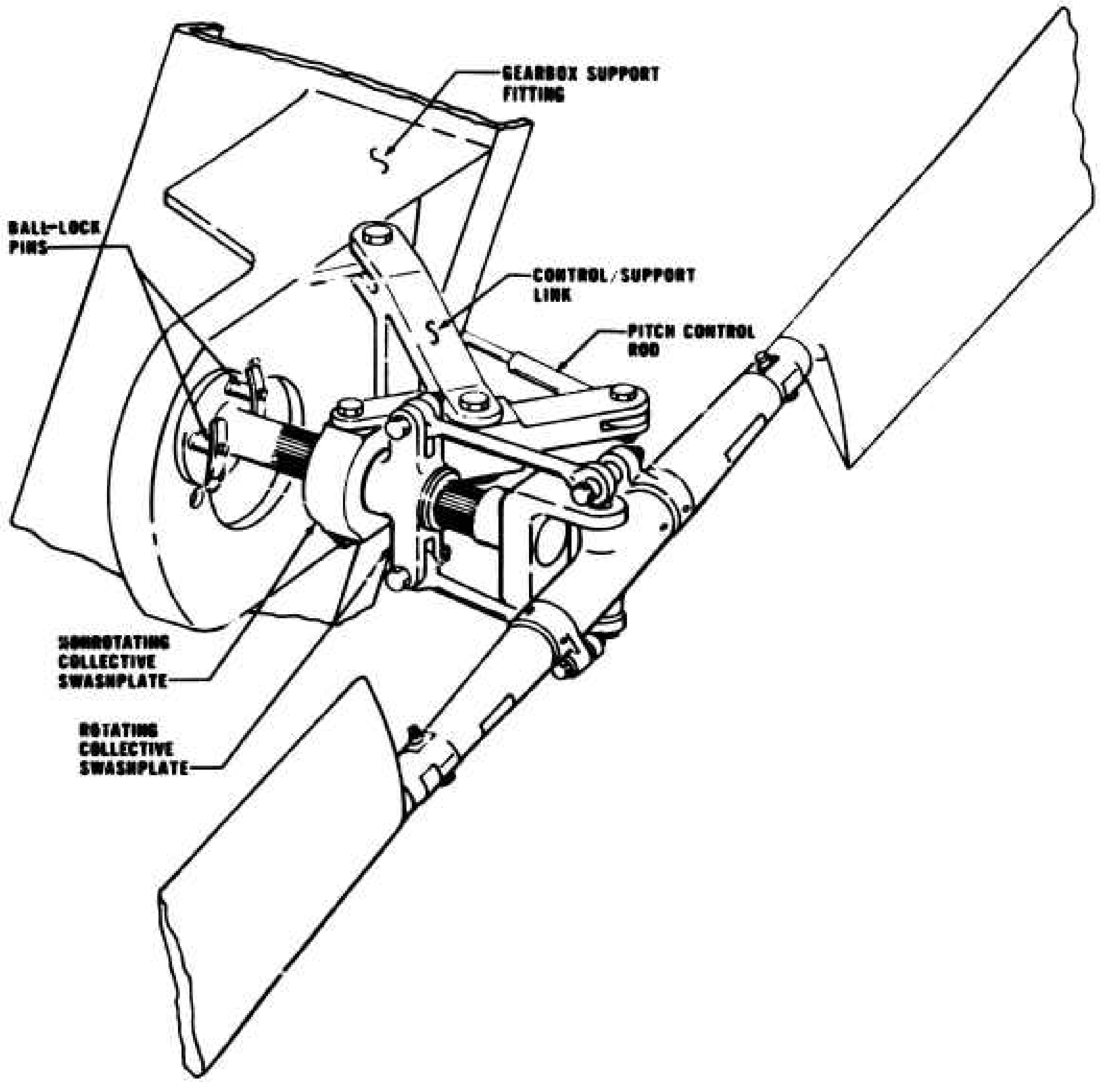


Figure 23. Stowed Tail Rotor With Tail Rotor Gearbox Removed.

### Stress

It is very probable that the segmented output shaft can be made to work. However, considerable attention will need to be devoted to its design and analysis, followed by extensive testing. As shown, the shaft is probably lighter than required.

### Aerodynamics

The heavy link which supports the swashplate is outside the contour of the tail pylon and therefore increases parasite drag. This effect can be minimized by local fairing where the link attaches to the pylon structure. Without fairing, high-speed performance and range might be affected by about 1 percent.

### Weight

A weight increase equal to about 5 to 10 percent of original gearbox weight should be anticipated.

### Cost

Incorporation of this concept will increase the helicopter price by an estimated $2,000.

## Estimated Development Cost

Time - A program to develop the recommended concept could best be conducted by a prime helicopter manufacturer. Carried through to flight test, the program will require approximately 20,000 man-hours expended over a 36-month period.

Dollars - A development program of the size indicated above will cost approximately $500,000.

Success Probability - Moderate.

## Estimated Improvement Potential

Based only on the estimated recurring cost differential of a modularized tail rotor gearbox, the concept might be economically worthwhile. The design success probability is estimated to be only moderate, however. This, coupled with the high development cost projection, makes it a poor candidate for further development at this point. The concept might be considered as part of a future tail rotor gearbox design effort, however, when the added development cost that it would incur would be substantially smaller.

## DRIVE SHAFT ALIGNMENT INDICATOR

The objective of this study was to develop a concept for rapid and positive indication of main drive shaft alignment in the helicopter. Constraints imposed on the concept were that the indicator be "built-in" and that it function visually or by feel without recourse to external special tools. Other goals included the capability of checking alignment with the shaft installed and a minimal requirement for access to the shaft area.

### APPROACHES CONSIDERED

Nine design approaches were considered. These fell generally into five generic groups:

1. Mechanical Indicators
2. Consumable Indicator
3. Indicator Employing a Strobe Light
4. Indicators Employing a Diffused Light Source
5. Indicators Employing a Columnar Light Source

### Mechanical Indicators

Several concepts of this type were examined. They generally involved loose items of equipment such as a straight edge, feeler gage or measuring pins. In all cases, good access around both ends of the shaft was needed. All of the devices permitted only a static check of alignment. None could be used during operation of the shaft.

Mechanical indicators were observed to require a relatively higher level of inspection skill than most of the other concepts examined. The direction and magnitude of transmission or engine shift required to bring alignment into tolerance would not be obvious to the inspector. A reference chart or table would be necessary. A complete recheck of alignment would be required each time the location of the transmission or engine was adjusted.

Mechanical indicators promised to be the least costly concept to develop and produce, but because of the more significant disadvantages mentioned above, none were considered to be serious contenders for further development.

## Consumable Indicator

One device was conceived which utilized replaceable syntactic foam rings at each end of the shaft. A misaligned, rotating shaft would contact one of the stationary rings and leave evidence of such contact.

Support brackets would be bulky and become obstacles during other routine maintenance. The consumable rings would need to be stocked in quantity because a multiple number might be used during the process of making a single alignment adjustment. This concept was judged not to be effective for static check of alignment.

The only notable advantage to this type of alignment device is the record it provides of random erratic shaft displacements during operation. All factors considered, this concept was not considered worthy of further study.

## Indicator Employing a Strobe Light

One device examined utilized a strobe light to illuminate a spherical tipped stem extending from the flexible coupling into the shaft interior. Stripes painted on the sphere would be visible through viewing ports in the shaft when alignment was within tolerance. Inability to see the stripes would indicate that adjustment was necessary.

The greatest deficiency observed in this design was that an out-of-tolerance indication did not concurrently indicate in what direction the correction must be made. Other disadvantages were the requirement for loose equipment (strobe light), the inability to make a static alignment check, viewing ports (holes) in the shaft which would allow entry of corrosive elements and dirt, the possibility of dirt obscuring the paint stripes on the ball, and the need for access (line of sight) through the axis of the shaft in a horizontal plane.

Because of the many obvious disadvantages inherent in this concept, it was abandoned early in the study.

## Indicators Employing a Diffused Light Source

Two devices were investigated which employed an ordinary light source such as a standard, hand-held flashlight. The simpler device of the two incorporated a spherical-tipped stem extending from the flexible coupling into the shaft body. In-line holes through the shaft body and the internal sphere allowed light to pass when the shaft was aligned. The amount

of passed light decreased with increasing misalignment until the tolerance limit was indicated by complete blockage of lignt. The overriding disadvantage of this design was its inability to indicate the direction in which adjustment must be made.

Another concept involving the use of a flashlight incorporated a ring of light-collecting material on the rotating shaft. Protruding from a single point on the ring was a fiber-optic light emitter. The emitted beam of light struck a stationary target area on the transmission or engine. If the dot of light remained within a prescribed target area as the shaft was rotated through one revolution, the alignment was acceptable. If the dot left the target circle, an excellent indication was given to the mechanic as to the direction and extent of correction which must be made. The light collector/emitter ring design was not selected for further study primarily due to the high development risk involved.

Indicators Employing a Columnar Light Source

Several designs were conceived using columnar light. One variation placed the light emitter on one end of the engine with the light beam passing through the engine, the drive shaft and the transmission. Misalignment caused blockage of the light due to a shift in position of "peep" holes on the centerline of rotation of the flexible couplings. This device was rejected because of its inability to indicate the direction and magnitude of needed adjustment.

Another variation utilized a discrete light source transmitter fixed on the transmission or engine. Its beam of light was directed upon a reflective ring which, due to its shape, split the beam and directed each part into two translucent plastic rings, one on the inside and the other on the outside of the beam splitting ring. A difference in brilliance between the two translucent rings indicated some misalignment but not in excess tolerance. Illumination of only one ring meant that alignment adjustment was needed. This scheme was thought to involve very high development risks and for this reason was not pursued. The third concept employing columnar light placed both the light emitter and the target area on the transmission. This concept offered many distinct advantages over the others investigated and was selected for further study as described below.

SELECTED CONCEPT - COLUMNAR LIGHT BEAM AND TARGET

A receptacle for plug-in of a standard flashlight is provided at any convenient spot in the transmission area. (See Figures

24 and 25.) Light is collected in the receptacle and transmitted via glass fibers to an optical device imbedded in the transmission housing. Light leaving the optical emitter strikes a highly reflective surface, located on and at a right angle to the shaft body, and then bounces back to the transmission. If the light dot strikes the inboard target and is within the prescribed area, alignment of the forward coupling is acceptable. If the dot is outside the inboard target circle, adjustment to correct alignment of the forward coupling is required.

To check alignment of the aft coupling, the engine to transmission shaft is rotated approximately 120 degrees to allow the emitted light beam to strike the second reflective surface which is perpendicular to the centerline of the engine output shaft. The reflected beam of light should produce an illuminated dot in the outboard target area. If not, adjustment to correct the alignment of the aft coupling is required.

## Benefits

This concept would vastly simplify drive shaft alignment checks and, because it would tend to produce more precise alignments, enhance reliability.

### Maintenance

The light dot on the target area gives the mechanic an excellent indication of the direction of correction that is required. Further, since the shaft need not be rotated during the check, the mechanic may leave the flashlight illuminated while shifting engine location and concurrently observe the effect on shaft alignment. It is not necessary for the mechanic to have working space (access) around the shaft during the alignment check. He only needs to have the two target areas in view. Both are located on the transmission input housing.

The device works equally well while the shaft is operating. As in a static check, a dynamic check also displays lighted, stationary dots on the target areas (both dots simultaneously). This feature will permit alignment checks, involving no more than a glance, during Maintenance Operational Checks (MOC's).

### Reliability

Unquestionably, more precise alignment of flexible couplings will increase their service lives. In the case of lubricated couplings, such as the "crowned tooth, sliding

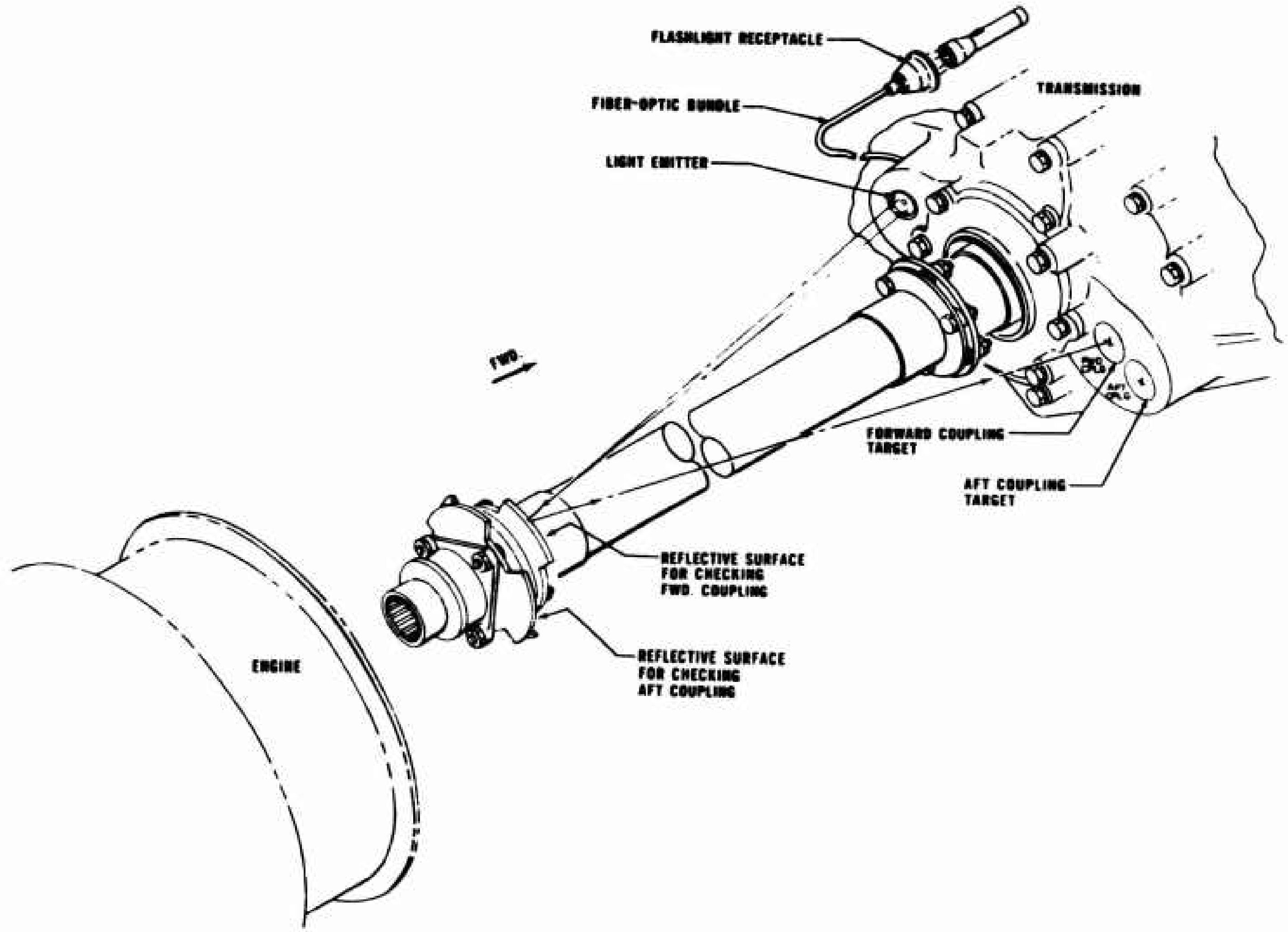


Figure 24. Shaft Alignment Indicator.

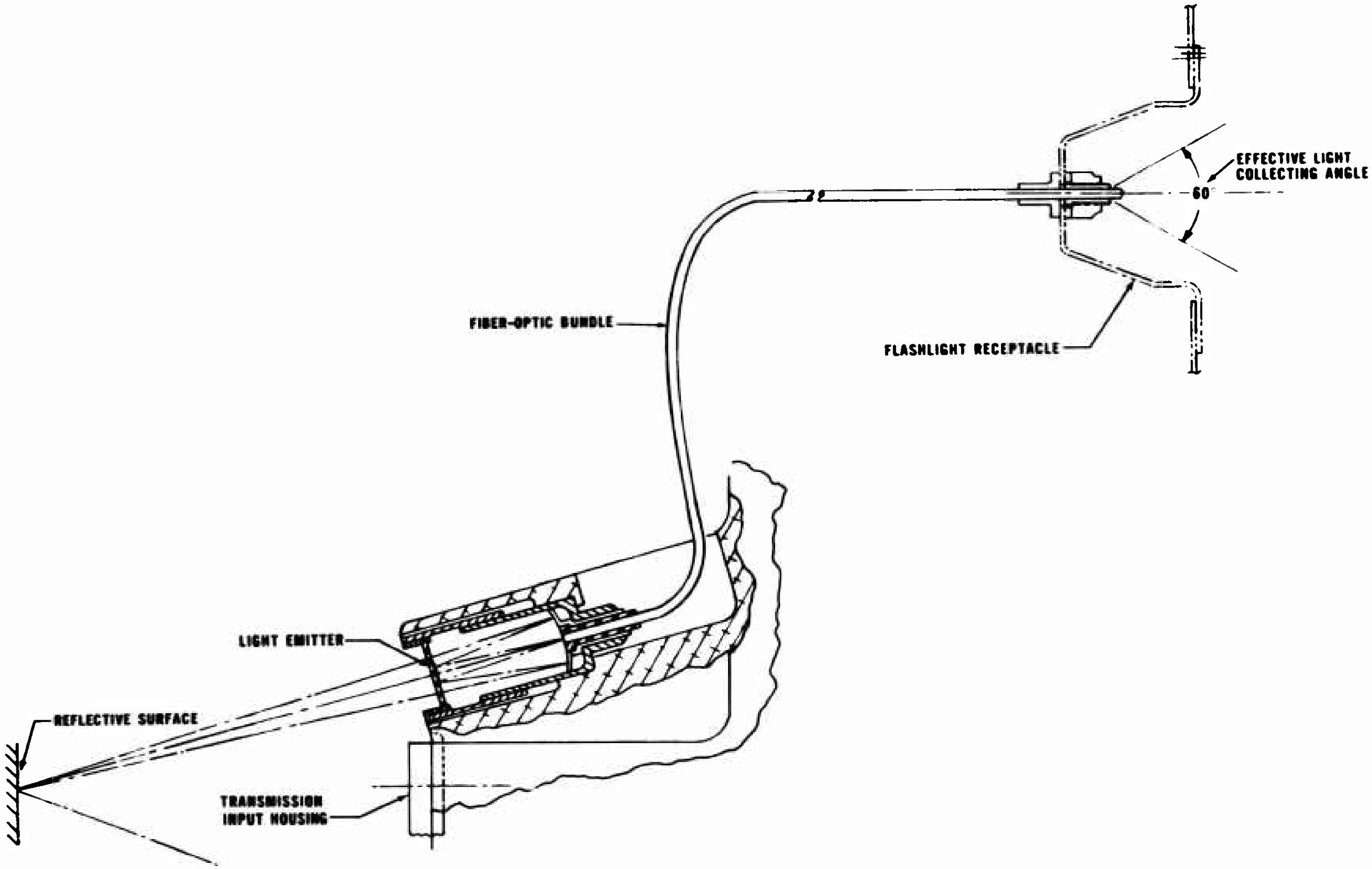


Figure 25. Sectional View of Light Collector and Emitter for Shaft Alignment Indicator.

spline" type, it is probable that lube intervals may be extended.

The alignment device installation itself can be designed to be very rugged. The light emitter can be buried in transmission housing during manufacture. Target areas may consist of nothing more than spot-faced surfaces on the housing having an engraved reticle and target circle. The only wearout item in the system is the light source. This is the mechanic's personal flashlight which is quickly attached and detached from a universal receptacle in the transmission area.

## Penalties

The penalties associated with the application are relatively minor, involving primarily slight weight and cost increases.

### Maintenance

Installation of a transmission will involve an added requirement, namely, hookup of a fiber-optic bundle to the light emitter embedded in transmission housing. At the start of each alignment check, the mechanic will need to wipe clean the emitter lense and the reflector surfaces.

### Weight

Addition of the flashlight receptacle, fiber-optic bundle, and optical emitter is expected to add less than 2 pounds to the flyaway weight of the aircraft.

### Cost

It is estimated that incorporation of the recommended device will increase the price of a helicopter by no more than $500.

## Estimated Development Cost

Time - A development program should involve an airframe manufacturer as prime contractor with significant support from an optical device manufacturer as subcontractor. It is estimated that a system can be developed, tested, and demonstrated in an Army helicopter with the expenditure of 5,000 to 6,000 man-hours over a 12-month period.

Dollars - Completion of the development program briefly described above should cost under $150,000.

Success Probability - High.

Estimated Improvement Potential

It is estimated that the drive shaft alignment device, if successfully implemented, would produce man-hour savings and reliability improvements greatly in excess of its development and recurring costs.

## GAP ADJUSTMENT MECHANISM FOR LENGTH-SENSITIVE COUPLINGS

The objective of this study was to develop a concept for installation of length-sensitive, flexible couplings without using shims to compensate for axial position differences. One important feature sought was the ability to make the gap-filling adjustment without first requiring that the gap be measured. Also, the optimum design should permit the gap adjustment to be made simultaneously with installation of the coupling rather than beforehand as is now the case. Other goals included the requirement for mechanic's standard hand tools only and the use of the fewest number of fasteners.

## APPROACHES CONSIDERED

This design study produced sixteen design variations which can conveniently be grouped into six categories:

1. Spline with threaded mechanism for making axial adjustment and for locking the coupling in position.

2. Floating spline with threaded mechanism used only for locking the coupling in the desired axial location.

3. Floating spline with bolts through slots for locking the coupling in the desired axial location.

4. Floating spline not locked, but centered via compression springs.

5. Floating spline and gland nut with elastomer material in shear for fixing the axial position of the coupling.

6. Floating split spline with clamp for locking the coupling in desired location.

### Axial Adjustment via Threaded Mechanisms

Several concepts of this type were considered. They all involved a female spline which slid axially on a male spline to compensate for shaft length differences. Transmission of all torque was through the mated splines, and each design employed some form of threaded mechanism for changing relative axial positions of the splines.

These devices all had a common and unacceptable fault. Any of the threaded mechanisms, actuated by an unskilled or unwary

mechanic, could easily compress a length-sensitive coupling beyond acceptable limits, causing it to be overstressed.

Floating Spline Locked via Threaded Mechanism

Three designs were investigated which employed some form of threaded device used only to lock free-floating splines after they assumed a natural, relative axial position which created no stress in the flex coupling. One device consisted of a nut with a tapered thread acting on a split collar. The other two devices employed a thread-driven wedge to cause a collar to grip the drive shaft.

The first device was unreliable because it was possible to inadvertently change the adjustment during the locking process. The remaining two devices required an additional safety or locking mechanism. This added complexity and degraded reliability. All three devices required the use of a nonstandard spanner type wrench.

Floating Spline Locked via Bolt Through Slot

One design consisted simply of a free-floating female spline on a male spline which were locked in the desired axial relationship by a bolt and nut. The bolt passed through slots in the coupling with the female spline and through holes in the shaft with the male spline.

Two significant faults were associated with this device. First, it relied completely on a marginal amount of friction to prevent axial movement. Second, the bolt slots and holes had to be located in critical areas and might become troublesome stress risers.

Floating Spline Centered via Springs

This approach utilized a compression spring on the flex coupling at each end of a drive shaft. The automatic self-centering feature of this concept was attractive. However, some doubt was felt regarding the length of service life such an arrangement was capable of providing.

The loose, unlocked splines operating in a vibratory environment would be subject to considerable fretting wear. But, more importantly, the reliability of the length-sensitive couplings might be compromised due to the compressive load, however light, exerted by the springs.

## Floating Spline Locked by Elastomer Material Under a Gland Nut

This scheme utilized a threaded gland nut to force elastomer material into a circumferential groove machined into the shaft and another machined in the I.D. of the coupling hub. After conforming to the shapes of the cavities, axial movement of the coupling could occur only if the elastomer failed in shear. Shaft torque would be transmitted by conventional splines which would be allowed to float prior to tightening of the gland nut.

This scheme was dropped from further consideration because it was felt that all adjustments after the first would be difficult to make due to the hysteresis of the elastomer. This occurs particularly if the elastomer has been under load for a prolonged period of time.

## Floating Split Spline With Clamp

Several designs were conceived which incorporated a female spline split axially in two or more places. The female spline was allowed to seek its natural axial position on a male spline, after which a clamp on the O.D. of the female spline was tightened. This caused the female spline to grip the male spline in collet fashion.

The difference between split spline designs was primarily with the type of clamp used. These ranged from integral bosses with threaded bolt holes to band straps with overcenter latches. Evaluation of these devices resulted in selection of a bolted, split-collar clamp discussed below.

## SELECTED CONCEPT - SPLIT SPLINE WITH SPLIT COLLAR CLAMP

Figure 26 provides an artist's conception of a typical application of the selected concept. As shown, the rigid flange for attachment of the flex coupling has an elongated, cylindrical hub. In the I.D. of the hub is machined a female spline. On the O.D. is machined a circumferential groove to accept two halves of a bolted collar clamp. Several axial slots are cut through the hub wall, starting at the end opposite the rigid flange and terminating just before reaching the flange.

During installation of a shaft having length-sensitive couplings, the clamp bolts are left loose until the split spline coupling finds its natural axial location on the gearbox input shaft. This adjustment is automatically achieved and is complete when the length-sensitive coupling feels neither compressive nor tensile forces acting upon it. Tightening the clamp bolts at this point causes the split female spline to grip the gearbox input shaft in collet fashion, thereby retaining its axial location.

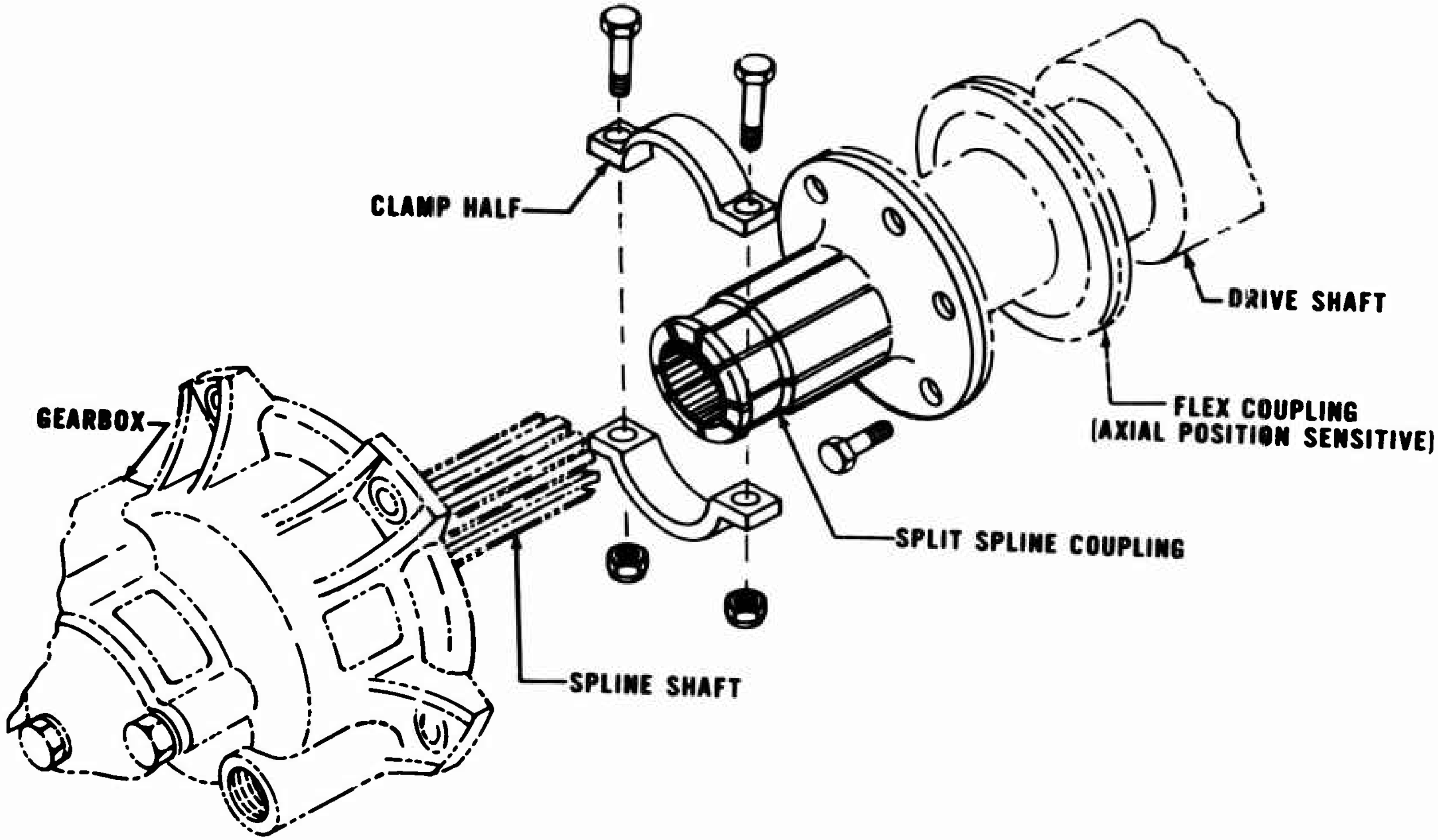


Figure 26. Gap-Compensating Device for Length-Sensitive Flexible Couplings.

## Benefits

The advantages offered by the proposed design primarily result in improved maintenance and greater coupling reliability.

### Maintenance

The proposed gap-compensating device simplifies the process of installing drive shafts having length-sensitive flexible couplings. Typically, such installations involve (a) initial installation of the shaft, (b) feeler gage measurements, (c) a calculation to determine average measurement, (d) selection of shims, (e) removal of the shaft, (f) removal of the rigid flange coupling, (g) installation of shims, (h) reinstallation of the rigid flange coupling, and finally (i) reinstallation of the shaft. This lengthy procedure has been replaced by one which requires simply (a) installation of the shaft and (b) tightening of the collet clamp bolts.

The bolts used to secure the collet clamp are at right angles to the drive shaft; therefore, the shaft need not be restrained while the bolts are being torqued. No special sockets or wrenches are required.

### Reliability

The length-sensitive flexible couplings which operate next to the proposed couplings will very likely enjoy longer service lives for two reasons. First, the possibility of improper shimming and subsequent operation in an overstressed condition has been eliminated. Second, the simplified installation procedure allows the shaft to be installed half as many times as previously required. The rate of maintenance-induced damage should decrease accordingly.

## Penalties

The penalties associated with this concept are relatively minor and appear to be amenable to improvement during a development program through refinement of the collet design.

### Maintenance

If wear steps should occur on the male spline due to fretting, it might be difficult to reposition the collet axially.

### Reliability

The number of female spline teeth in heavy contact with the male spline is limited due to the type of clamp used. Clamp-up is essentially in one plane, and fretting and loosening may occur. The shaft spline is not sealed and corrosion may also become a problem.

### Stress

As shown, the splits in the hub are severe bending stress concentrations, responsive to torque, and could become a low-cycle fatigue problem.

### Weight

Approximately one-half pound of weight will be added to each coupling having the recommended collet design.

### Cost

It is estimated that the price of a conventional rigid flange coupling will increase by about $100 if the proposed concept is adopted.

## Estimated Development Cost

Time - A program to develop the recommended gap-compensating device would best be conducted by a prime helicopter manufacturer. Such a program, carried through to the flight test stage, should require approximately 3,500 to 4,000 man-hours expended over a 12-month period.

Dollars - A development program of the magnitude described above would cost under $100,000.

Success Probability - Moderate.

## Estimated Improvement Potential

It is estimated that the flexible coupling gap-compensating mechanism could, if the remaining technical problems are overcome in development, produce life-cycle cost savings in man-hours and extended coupling life which are significantly greater than the required investment costs.

## SPLIT BEARING FOR TAIL ROTOR DRIVE SHAFT

The objective of this study was to develop a concept for a tail rotor drive shaft bearing which could be replaced without first having to remove the shaft. The concept would be particularly attractive for installations comprised of a long, single-piece shaft supported by several bearings slipped onto the shaft in series. Constraints imposed on the concept included a requirement for a self-aligning capability at initial installation. Also, use of special tools was to be minimized.

### APPROACHES CONSIDERED

Six design variations evolved from the split bearing concept study:

1. Roller bearing, two-piece bolted housing clamp, single function outer race, inner race between shoulder and nonreplaceable spanner nut.

2. Ball bearing, two-piece bolted housing clamp, multifunction outer race, inner race between shoulder and nonreplaceable spanner nut.

3. Ball bearing, one-piece split housing clamp, multifunction outer race, inner race between two nonreplaceable spanner nuts.

4. Ball bearings, "V" band housing clamp, multifunction outer race, inner race between two nonreplaceable spanner nuts.

5. Ball bearing, two-piece housing clamp with band strap, multifunction outer race, inner race between shoulder and nonreplaceable spanner nut.

6. Ball bearing, two-piece housing clamp with band strap, multifunction outer race, inner race between two replaceable spanner nuts.

This concept study was selected to illustrate the typical evolution of a design candidate. The following paragraphs describe the various design iterations which culminated in the winning concept.

## Approach Number One - Split Hanger Bearing

Figure 27 illustrates the first approach toward a split hanger bearing design. The design evolves around a roller bearing which has its inner and outer races split axially in two places. The rollers are captured in a flexible nylon cage which is split in one place. A collar, fixed to the shaft, is precision ground to control roundness and concentricity of the inner race. The inner race is secured to the collar by a special spanner nut which, after being torqued, is locked in place by a wireform locking pin.

The bearing outer race is held by a two-piece bearing body which further provides self-aligning capability via its spherical O.D. The bearing body also has grooves in its I.D. which contain O-rings for sealing purposes. The O-rings are split in one place. Two flat gaskets are utilized between the body halves to help contain the bearing grease. Holding the body halves together is a two-piece bolted clamp which provides the spherical seat for the self-aligning feature of the bearing body.

Analysis of this design revealed many unacceptable faults. To begin with, the conical surface of the shoulder on the fixed collar would be extremely difficult to machine to the required close tolerances. In applications involving a number of collars fixed to a single shaft, replacement of all but one of the spanner nuts would be impossible. The nuts are trapped on the shaft by the collars. Further, the flat gaskets between bearing body halves are loose items and are very likely to be pinched between the bearing outer race halves during assembly. This would cause the outer race to assume an oval shape, seriously affecting its reliability.

Continuing with the design faults, it was observed that both O-rings rub against metal sealing surfaces which cannot be replaced if they become worn. Lastly, a ball bearing is preferable to a roller bearing in this application, because some axially applied forces may act upon it.

Based on the above, design number one was not considered to be a viable candidate in the split hanger bearing study.

## Approach Number Two - Split Hanger Bearing

Figure 28 depicts split hanger bearing number two. This design incorporated several features which eliminated faults found with the first design. The improvements are discussed below.

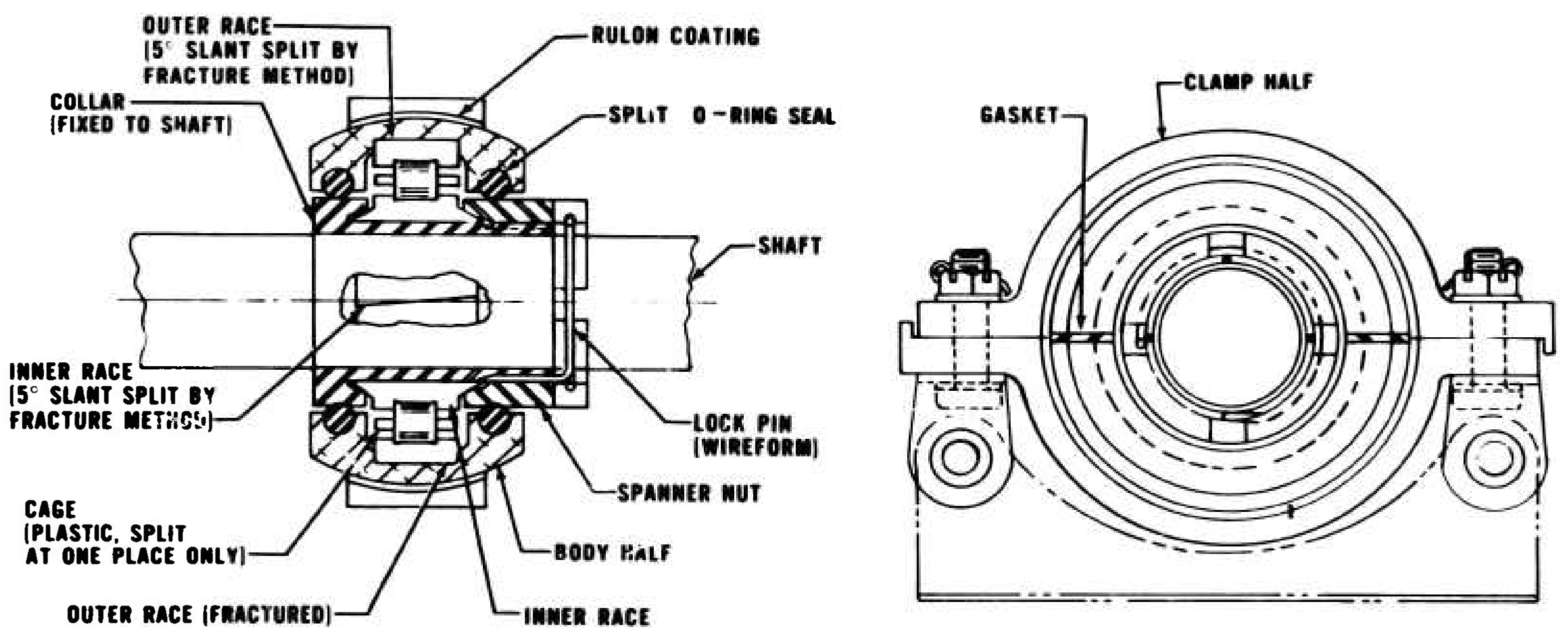


Figure 27. Candidate Number 1, Split Hanger Bearing Design.

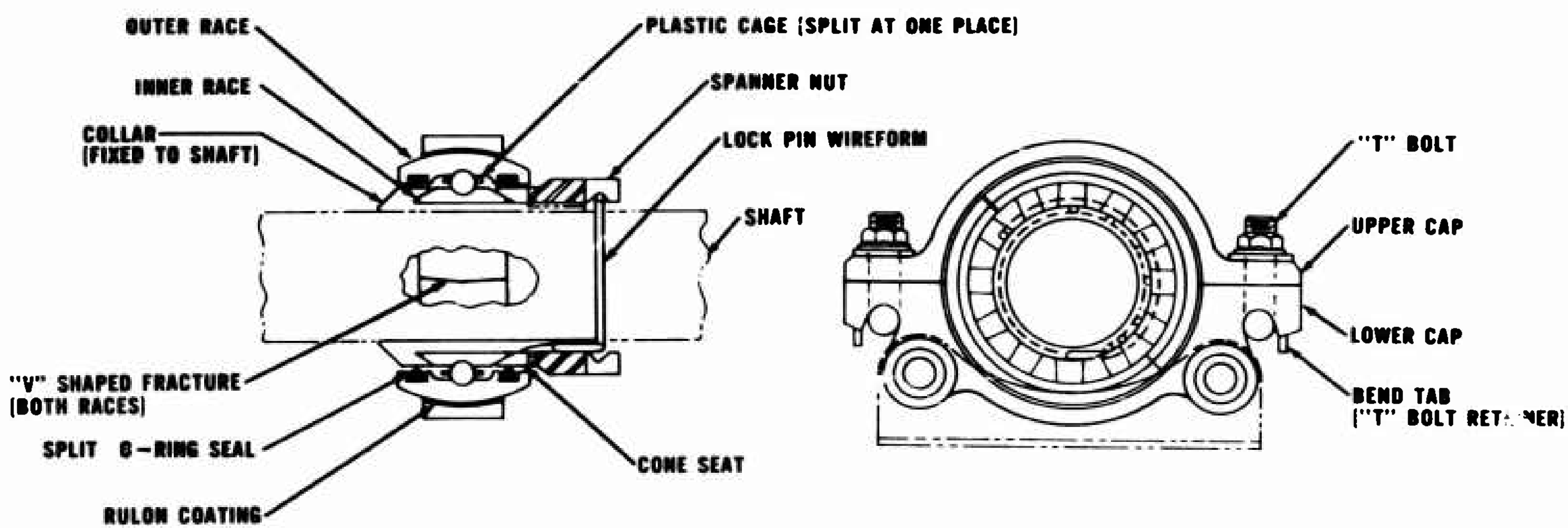


Figure 28. Candidate Number 2, Split Hanger Bearing Design.

A ball bearing replaced the roller bearing to accommodate axial loads which might be expected to occur in a tail rotor drive shaft installation. The outer race of the bearing was redesigned to perform all of the functions previously performed by the bearing body. This complicated manufacture of the race, but had a positive net effect due to elimination of the bearing body.

One O-ring in design number one rubbed against the O.D. of the spanner nut. The concentricity (runout) of this sealing surface was controlled by two factors which might possibly be in conflict. These factors were the conical I.D. of the nut and the pitch diameter of the internal thread in the nut. Design number two eliminated this possible conflict by providing a cone seat separate from the spanner nut. Lastly, the troublesome gaskets between the body halves were eliminated. It was concluded that the tight metal-to-metal fit between race halves alone would effectively prevent grease leakage. The logic of this conclusion is that the outer race does not rotate, and therefore no centrifugal forces act upon the grease filling its cavity.

In spite of the noted improvements, design number two still possessed serious drawbacks which eliminated it from further consideration. Most importantly, the spanner nut and cone seat were captured on the shaft and could not be replaced. There remained the extremely difficult problem of grinding the conical surface in the shoulder of the fixed collar.

## Approach Number Three - Split Hanger Bearing

Figure 29 depicts split bearing design number three. This bearing is different from earlier designs in two respects. Earlier designs had the bearing secured against a fixed shoulder on the shaft. No adjustment of axial location was possible. Design number three alleviated this situation by securing the bearing between two adjustable spanner nuts. The earlier designs also had two-piece outer clamps. Unless special indexing devices were incorporated, it would be possible to incorrectly mate the two halves. Design number three utilized a one-piece clamp split in only one place. This change, however, was not necessarily an improvement. Now, entry of the bearing into the clamp had to be by the side (axially) rather than from the top. This could only be accomplished if the clamp was expanded by prying apart the faying surfaces at the split line. Also, custom shimming was required at the split line.

All factors considered, this design lacked appeal and was dropped from further consideration.

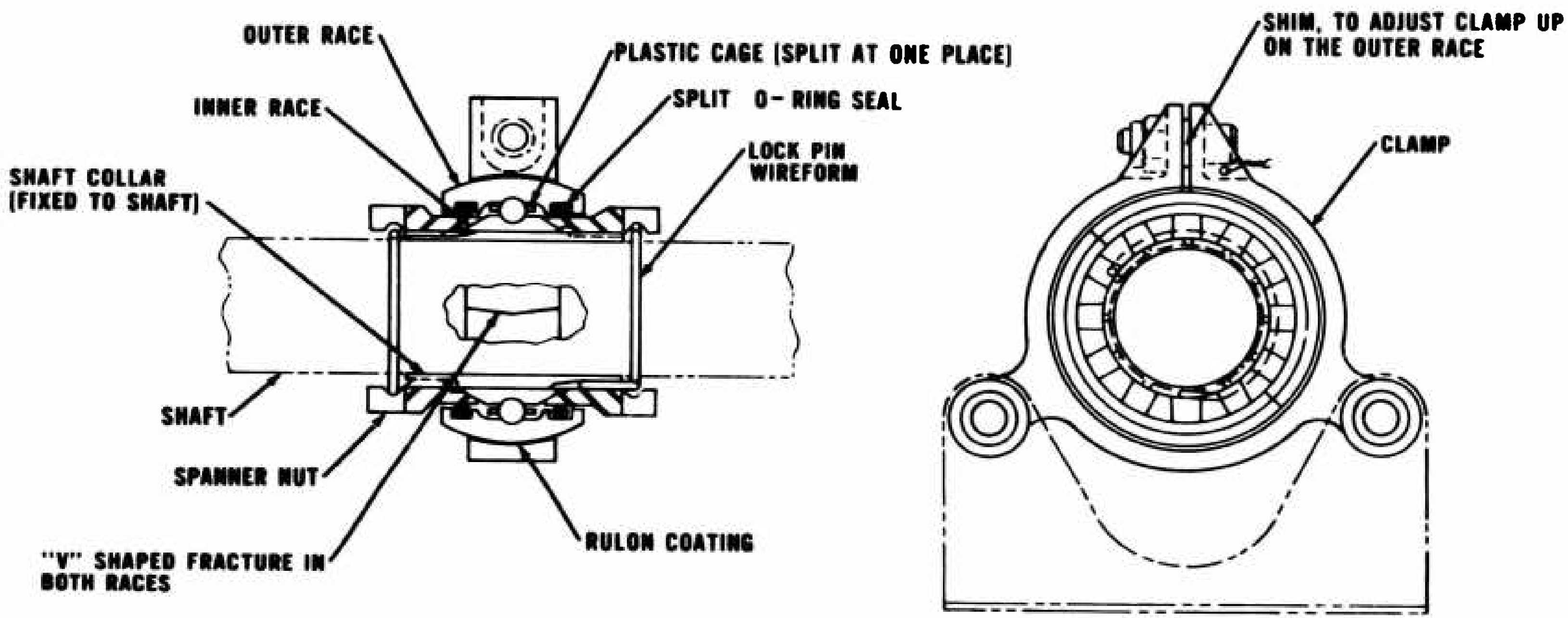


Figure 29. Candidate Number 3, Split Hanger Bearing Design.

## Approach Number Four - Split Hanger Bearing

Figure 30 depicts split bearing design number four. The only significant difference between this design and those described earlier is the type of outer clamp used. Here, a conventional "V" band clamp acts on two rings which form a mating "V" on the O.D. and a spherical seat in the I.D. A quick-acting "T" bolt is used to tighten the "V" band. Since this design was similar to the earlier designs in most respects, it too had many of the previously discussed faults. The improvement realized by incorporation of the "V" band was not sufficient to offset the faults, and this design was also dropped from further consideration.

## Approach Number Five - Split Hanger Bearing

Figure 31 depicts split bearing design number five. This design introduced a number of features not found on any of the earlier designs. All the earlier designs used wireform locking pins to safety inner race spanner nuts. Design number five used a self-locking type nut. Another improvement placed the wrenching slots on the face of the nut instead of on the O.D. This permitted use of a simpler design wrench which would remain engaged in the nut slots with much less effort on the mechanic's part. One major fault still remained and overshadowed the above improvements. This design, as did all others before it, captured spanner nuts and cone seats on the shaft. A damaged nut or cone seat required shaft scrappage.

This concept returned to the two-piece housing design (upper and lower caps), which was desirable because it allowed assembly of the bearing from the top (radially) rather than from the side (axially). Used with the two-piece housing is a band clamp with a single quick-acting "T" bolt. One more new feature found in this design is the labyrinth type seals used. Although innovative and attractive from the standpoint of eliminating the need to handle split O-rings, there was very little confidence that they would operate satisfactorily.

Analysis of the five candidate designs produced no clear winner in the selection competition. One final design therefore was begun. This last design was to be a composite, incorporating the best features of all preceding concepts. The resulting design is discussed below.

## SELECTED CONCEPT - SPLIT HANGER BEARING

Figures 32 and 33 depict the winner of the competition to select

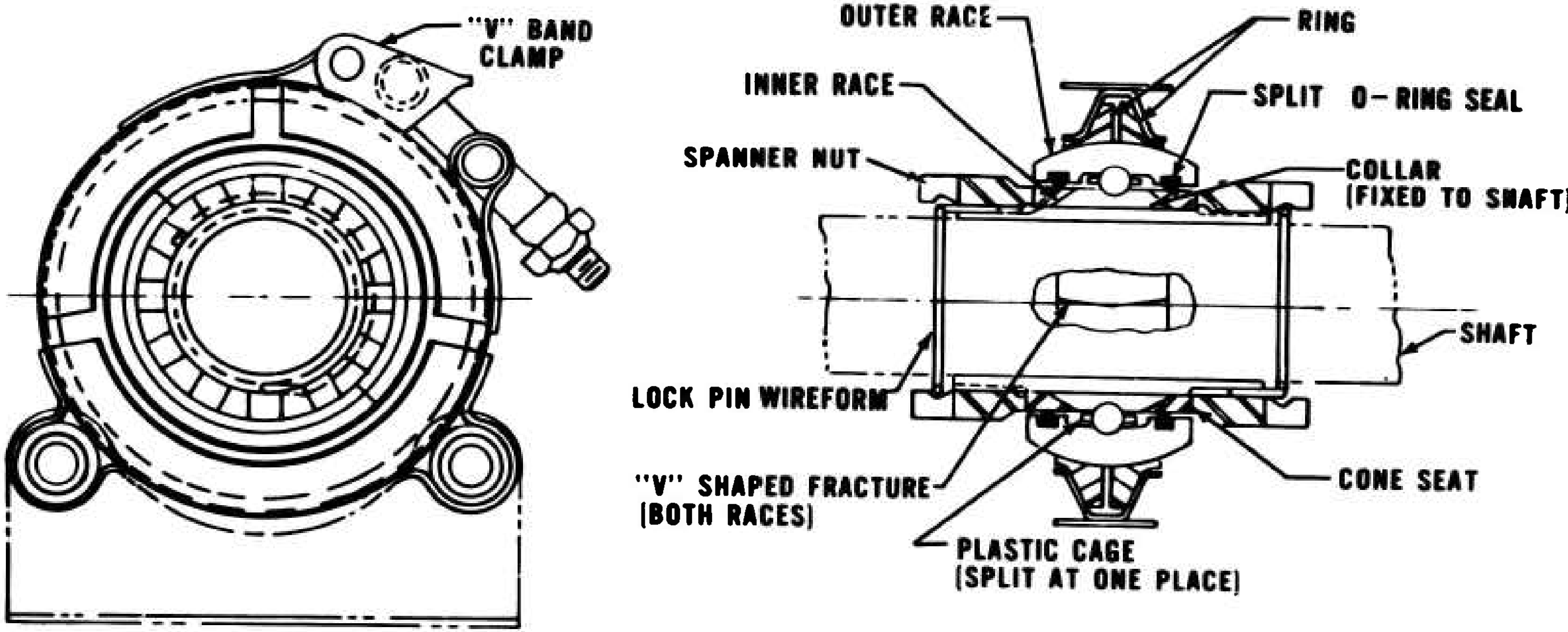


Figure 30. Candidate Number 4, Split Hanger Bearing Design.

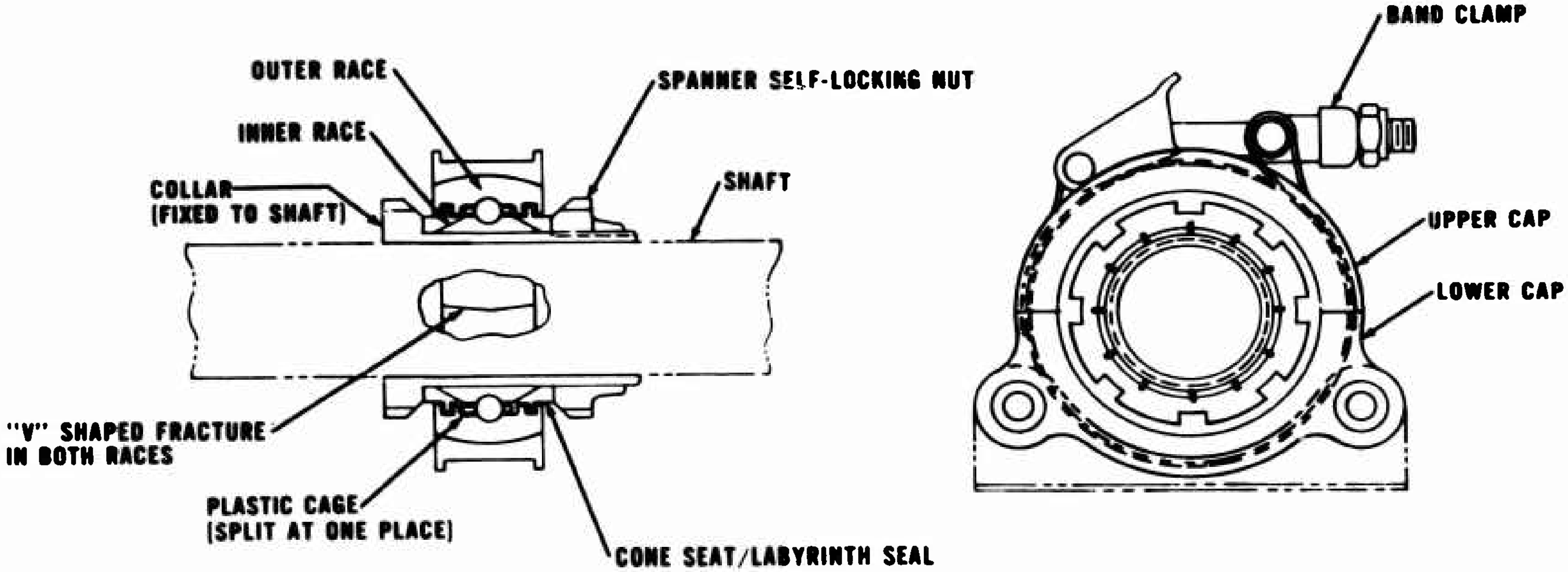


Figure 31. Candidate Number 5, Split Hanger Bearing Design.

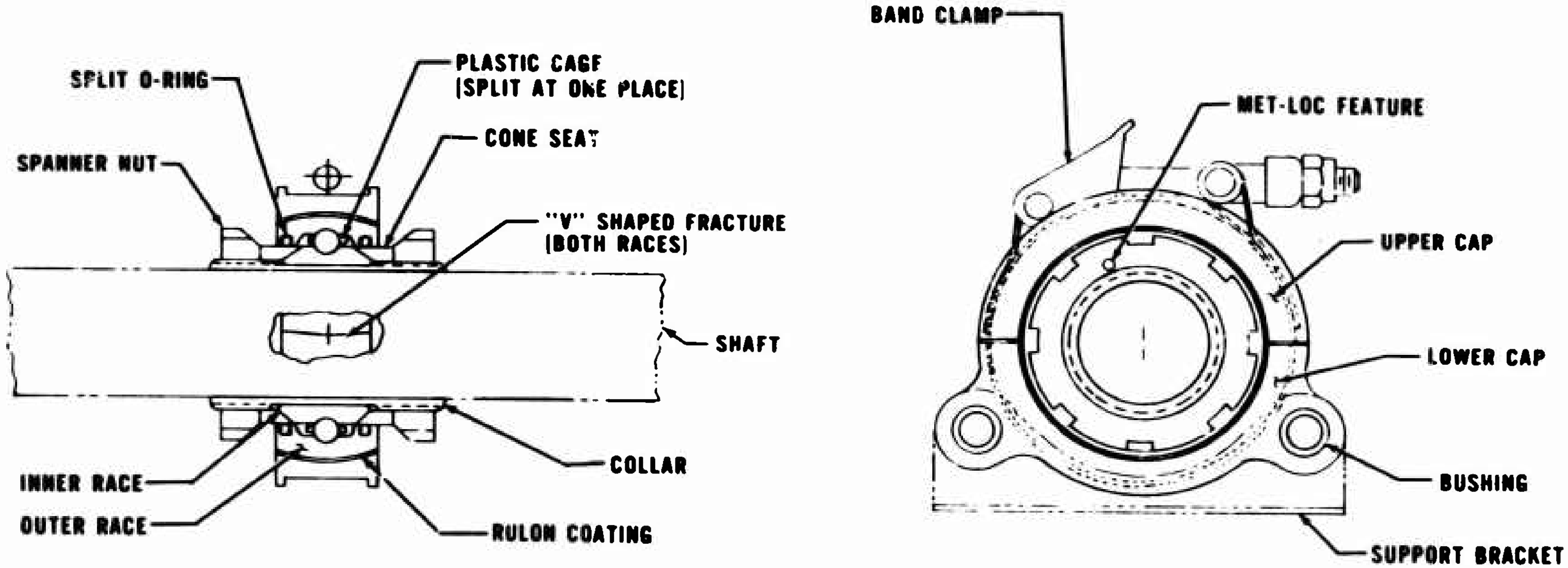


Figure 32. Selected Candidate, Split Hanger Bearing Design.

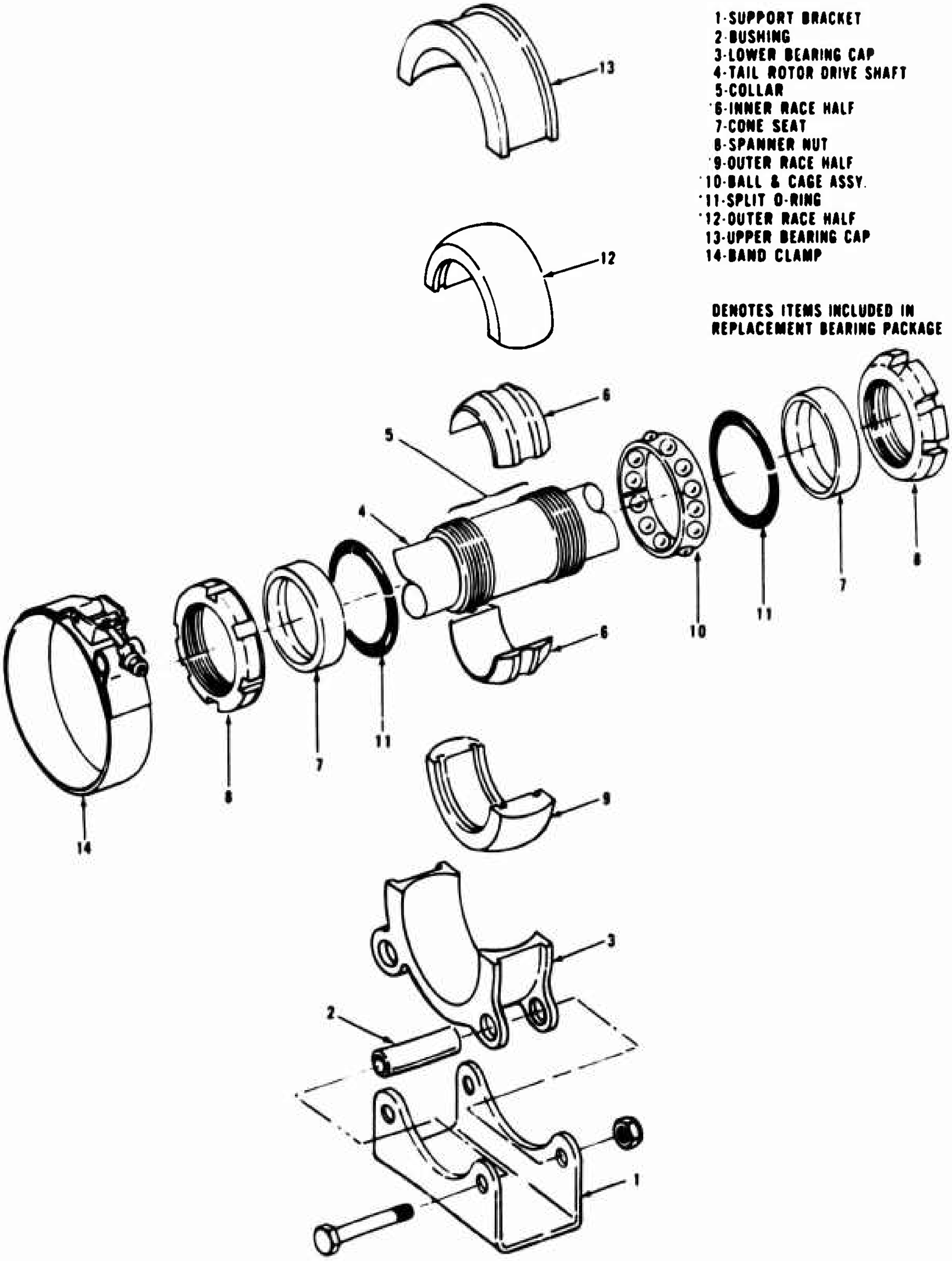


Figure 33. Exploded Isometric View of Selected Candidate, Split Hanger Bearing Design.

the most promising split hanger bearing design.

This concept features a fixed shaft collar which is undercut on its midsection to permit passage of spanner nuts when replacement of the nuts is required. The nuts are self-locking and have wrenching slots machined into their O.D. Cone seats, separate from the spanner nuts, act against the chamfered ends of the bearing inner race halves to retain the race halves to the shaft collar. The O.D.'s of the cone seats are precision ground and serve as rotating sealing surfaces on which the stationary O-rings ride. The O-rings are split in one place to permit installation around the shaft.

Nylon is used to form the ball retention cage. The cage is split in one place to permit installation around the shaft. The bearing outer race is split into two halves. The race is wider than normal to provide room for one O-ring groove on either side of the ball raceway. The O.D. of the bearing race is spherical and forms part of the self-aligning mechanism. The bearing outer races are held together by an upper and a lower bearing cap. The caps maintain race concentricity and roundness. A band clamp with a quick-acting "T" bolt fastener is used on the bearing caps.

## Benefits

The paramount objective of this concept development study was to ease the task of replacing tail rotor drive shaft bearings. This was accomplished at some expense in other areas as indicated later.

### Maintenance

The split design allows bearings to be replaced without removing the tail rotor drive shaft or disturbing adjacent bearings on the shaft. Only self-locking nuts are used. There is no requirement for lockwire or shimming.
The "V" shaped fractures in the races prevent incorrect installation. Bearings can be inspected to determine internal condition. O-ring seals are replaceable as detail parts, as are the metal sealing surfaces and spanner nuts.

## Penalties

The ability to replace bearings without removing the shaft was obtained at considerable expense in the following areas.

## Maintenance

Many loose parts must be handled and skillfully assembled. Mechanics assigned to this task will need to be well trained and experienced. Since grease must be added to the bearing during assembly, there is a real possibility of applying the wrong amount or introducing contaminants. This problem can be minimized, however, by supplying a tube of grease (exact quantity required) with each replacement bearing.

Replacement of the metal sealing surfaces (cone seats) and the spanner nuts is possible, as indicated earlier. To do so, however, requires that the shaft and possibly some bearings be removed as well. Special spanner wrenches are used on the nuts.

## Reliability

Interrupted ball raceways will unquestionably reduce the bearings' service life. Also, there is some doubt as to the split O-ring's ability to perform as well as expected. Grease leakage may become a problem. The self-locking spanner nuts must be "cycled" over several threads when being removed or installed. This reduces the effective life of the self-locking feature.

## Stress

Very tight tolerance control is required to ensure intimate contact between the shaft collar and the bearing inner race. If there is radial clearance between the collar and the race, the load path will be through the cone seats at the frictional contact at the spanner nuts. This condition is susceptible to fretting and loosening. The outer race split should not be in line with the housing split as shown in Figure 33. The outer race must be rigid enough to be relatively unaffected by the clamp load. Typical unbalance loads must transfer through the outer races and therefore will impose fatigue loads on the strap clamp which is ill equipped to resist them.

## Weight

The split hanger bearing configuration estimated weight is approximately 0.2 to 0.3 pound more than the standard configuration. This increase is for a single hanger assembly.

Cost

Shaft hanger assemblies of the type recommended will cost approximately $300 more per hanger than the conventional design.

Estimated Development Cost

Time - A program to develop a split tail rotor drive shaft bearing could best be conducted by a bearing manufacturer with support from a prime helicopter manufacturer in the test phase. An estimated total of 6,000 man-hours, expended over a 12-month period, would be required.

Dollars - A development program of the size indicated above would cost approximately $150,000.

Success Probability - Low.

Estimated Improvement Potential

Although succeeding in the original objective of facilitating drive shaft hanger bearing replacement, this concept introduces penalties which appear to render it technically and economically unfeasible. This, together with the low probability of developing a workable design, makes it an unattractive candidate for further study.

## RAPID REPLACEMENT ENGINE INSTALLATION

The objective of this study was to develop a means of mechanically guiding an engine to its mounting location and quickly securing it in place. The installed location of the engine was to be controlled sufficiently to allow elimination of the engine-to-transmission drive shaft alignment check. All fluid, air and electric line fittings were to be self-aligning and quick-connecting. The possibility of cross-connecting lines was to be eliminated. Great emphasis was to be placed on reducing required personnel skills and on minimizing reliance on special ground support equipment.

### APPROACHES CONSIDERED

Four design approaches were considered:

1. Vertical rails for "drop-in" engines.

2. Horizontal rails placed longitudinally on the fuselage.

3. Horizontal rails placed laterally under stub wings.

4. Pivoting support arches.

### Vertical Rails

In this approach, three "V" shaped vertical rails are used. Two on one side of the engine are permanently fixed to the fuselage, and the third on the other side of the engine is stowable. Combination roller and spherical bearing mount assemblies are supplied with the engine. Cradles for the spherical bearings are accurately located and permanently attached to the aircraft structure. Installation is accomplished by hoisting the engine above the rails, engaging the engine rollers in the rails, lowering the engine until the spherical bearings engage their cradles and, lastly, locking the bearings in place by bolting down bearing caps.

Several major drawbacks with this design soon became obvious. The vertical rails are, in fact, items of ground support equipment which fly with the aircraft. They, and the rollers on the engine, serve no purpose beyond guiding the engine during installation. Rolling motion of the engine during installation is not controlled and could become a problem if the rollers on one side of the engine "hang-up". The rails would be a nuisance to mechanics performing routine maintenance in the engine

area. Much work would be necessary to develop bearing mounts which could accommodate engine growth, twist, etc., during operation. For these reasons, the vertical rail concept was not pursued further.

Longitudinal Rails

This approach, similar to the one discussed previously, utilizes rollers on the engine to engage three "V" shaped rails permanently attached to aircraft structure. In this design, however, the rails are horizontal, one located on each side of the engine and the third underneath the engine. All three rails are flaired at the point where initial roller contact is made in order to present a larger engagement target area. The engine mounts are essentially spherical bearings fixed to structure which are "speared" by bayonets protruding from engine frames as the engine is pushed forward on the rails. Conventional thread and nut arrangements secure the bayonets in the I.D. of the spherical bearings.

The biggest disadvantage of this scheme, as with the first, is that the rails serve no purpose beyond guiding the engine during installation and are, in fact, pieces of flying special support equipment. Also, permanently installed rails on the sides of the engine limit access to the engine during routine maintenance and inspection. When weighed against the disadvantages discussed above, the small decrease in installation time afforded by this scheme did not warrant its continued development.

Lateral Rails

This design approach is best suited to helicopters with twin, pod-mounted engines. It requires a stub wing over each engine and two lateral rails attached to the underside of each wing. Installation is accomplished by raising the engine using a hoist or forklift and hanging it from the rails via rollers permanently attached to the top side of the engine. As the engine is pushed inboard, three bayonet type fittings engage spherical bearing blocks fixed to the fuselage. The bayonet-to-bearing block engagement is secured by quick-acting, hinged clamps. Manufacturing tolerances for the bayonet and bearing locations are small so that acceptable engine alignment is assured.

Simultaneously with bayonet-to-bearing block engagement, automatic coupling of mating halves of manifolded liquid, air and electrical lines occurs. A single threaded fastener maintains manifold security. This approach departed very little in principle from the two approaches discussed earlier. It

carried with it the same overriding disadvantages which discouraged further development.

## SELECTED CONCEPT - SWING-DOWN SUPPORT ARCHES

This concept is most adaptable to helicopters having twin, roof-mounted or podded engines. Figures 34 and 35 illustrate a potential installation.

The basis of the design is a pivoting arch-shaped structure which supports an engine and also forms part of the exterior surface of the fuselage when the engine is in its installed position. The support arch pivots at its lower end and, when swung down, extends horizontally from the side of the aircraft ready to receive an engine directly from a transportation trailer. An adapter is provided for the trailer to permit 90 degrees of engine rotation prior to attachment to the support arch. The attachment mechanisms are conventional links with rod ends and clevises. The links, however, have fixed lengths with no adjustment possible. Manufacturing tolerances on all items affecting engine location are held sufficiently close to assure acceptable alignment without adjustment.

The support arch, with engine attached, is raised or lowered by a hand crank which operates a harmonic drive unit mounted on the cabin door frame adjacent to the support arch. It rotates a link assembly which in turn controls the position of the support arch. Harmonic drive mechanisms are capable of very high reduction ratios (400 to 1) and are very suitable for the task intended.

When in the up position, the support arch engages precisely located fuselage fittings. Two quick-release, expandable bushing pins are used to secure the arch to the fittings.

All fluid, pneumatic and electrical lines, from the engine and from the airframe, terminate at a single point on the support arch under the engine. Located here is a manifold connector providing convenient and rapid attach/detach capability.

### Benefits

Several significant improvements are realized in the areas of maintenance and component reliability.

#### Maintenance

Engines may be moved from a transportation trailer directly to their installed locations on the helicopter without the

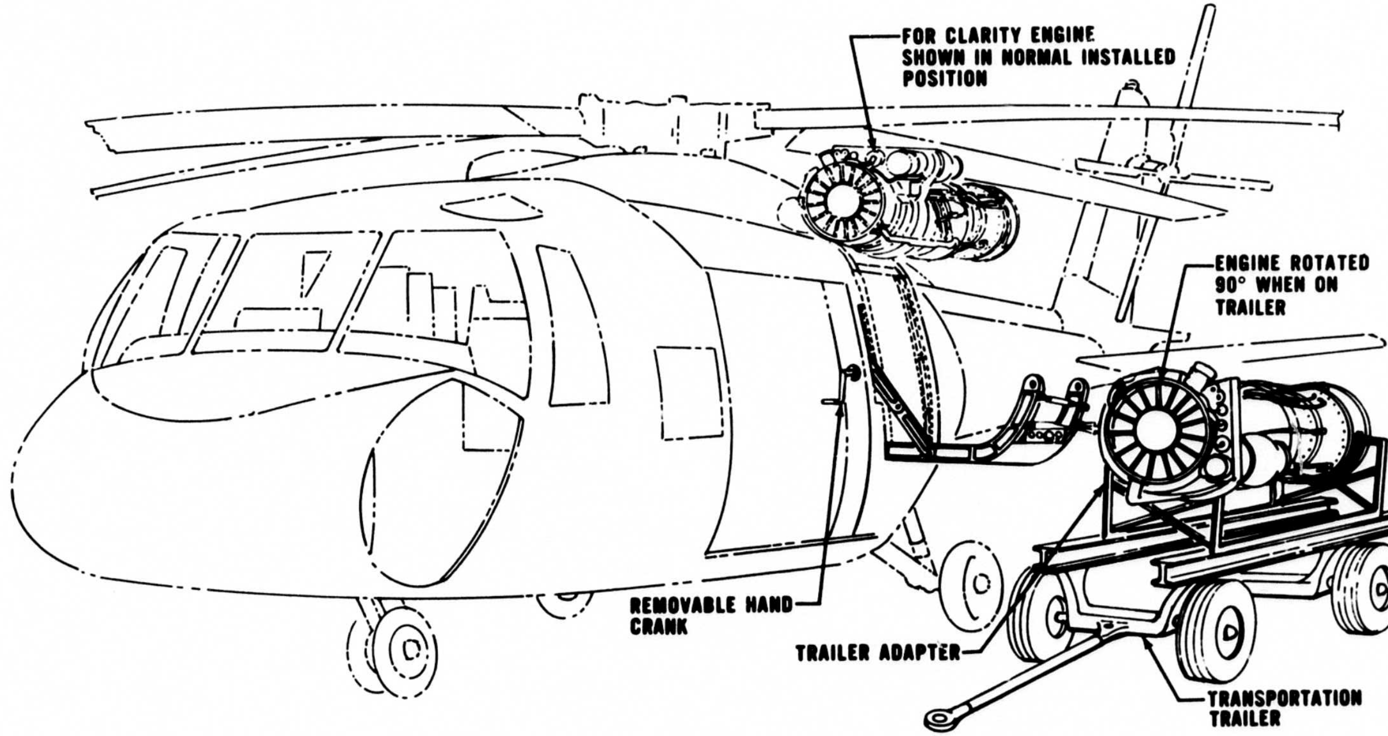


Figure 34. Swing-Down Engine Support Arches and Engine Transportation Trailer.

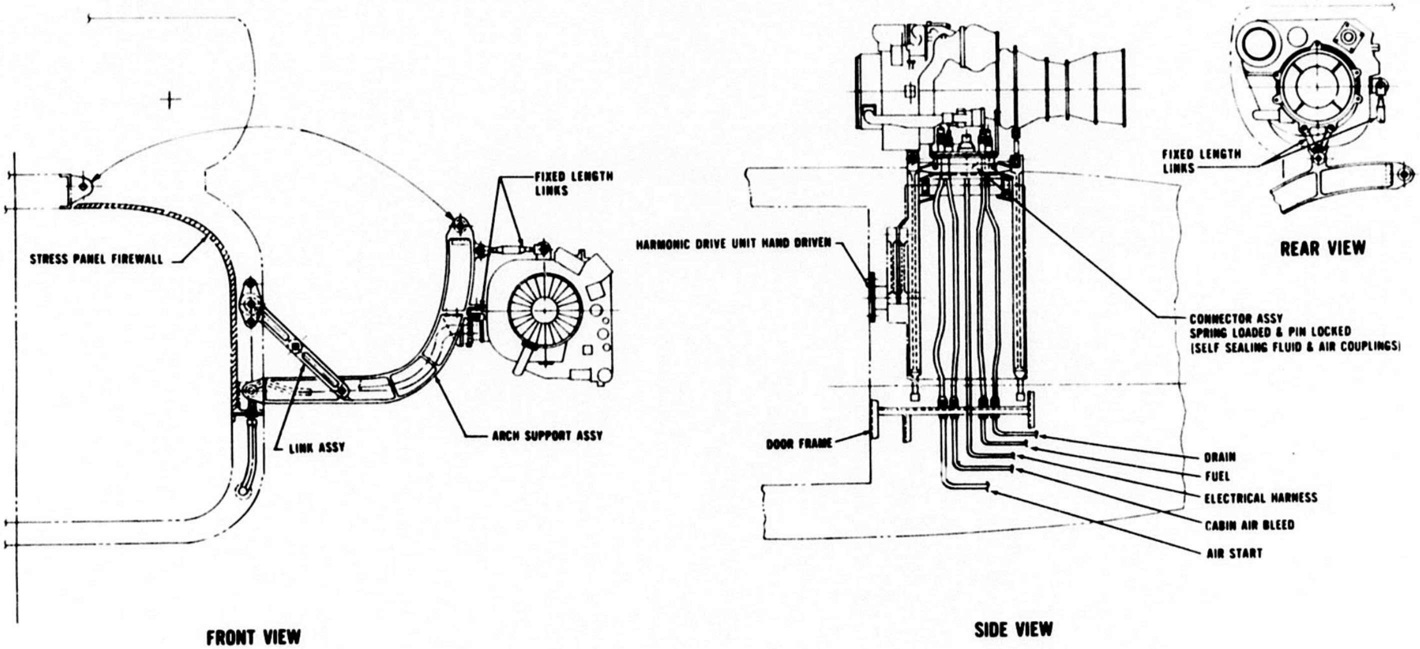


Figure 35. Views of Swing-Down Engine Support Arches in Orthographic Projection.

use of cranes, hoists, forklifts, etc. A very large portion of the overall task is performed by a mechanic standing on the ground manipulating parts which are at a very comfortable work height. In this work position, the engine is connected to the lowered support arch and all lines are connected by bringing together manifold halves. The links used to attach the engine to the support arch have fixed lengths and require no adjustment.

The harmonic drive unit, with its large speed reduction ratio, enables the mechanic to crank the engine up into position with very little effort. The main rotor blades need not be folded or positioned in any particular manner while the engine is being raised.

Quick-acting expandable bushing pins secure the support arch in its up position. All machined surfaces which affect relative engine/transmission location are precisely machined to ensure adequate alignment of the engine-to-transmission drive shaft. This alignment need not be checked after an engine change.

Leaks are most likely to occur at frequently disconnected fittings. In this concept all such fittings are grouped at the manifold under the engine. Access for inspection of these items is provided by a single panel.

<u>Reliability</u>

Engine-to-transmission shaft alignment is assured by close machining tolerances as indicated above. This will very likely have a positive effect on the service life of the shaft and may permit extended lube intervals (if lubricant is used).

Engine installation has been simplified sufficiently that fewer occurrences of maintenance-induced damages may be expected. This expectation is further reinforced by the fact that all work will be accomplished below the level of the main rotor, which reduces the potential for damage to rotor components.

## Penalties

Penalties are incurred in several areas. Most are minor, however, except for weight and cost increases.

<u>Maintenance</u>

A special adapter must be provided for transportation

trailers to permit engines to be rotated 90 degrees prior to attachment to the support arch. The concept requires a large working area on the side of the helicopter when attaching an engine. Inspection and lubrication lists need to be expanded to include the harmonic drive unit.

Reliability

When attached to the arches in the lowered position, engines are very vulnerable to damage by ground vehicles and personnel. All electrical and fluid lines bend through 90 degrees each time a support arch is raised or lowered. Special flex joints may need to be incorporated at the bend location.

Stress

To make room for retraction of the support arches, sections of stringers will be removed. The resulting loss of structural strength must be compensated for by use of stress panels and heavy reinforcement of skin and stringers around the cutout area.

Weight

This concept could add 75 to 100 pounds to the weight of a twin-engine helicopter. Aside from the relatively heavy arches, there will be some duplication of structure; the stress panel firewall in addition to external skin, for example. There also will be closing frames at each end of the cutout in addition to supporting frames. Lastly, the lengths of most lines, hoses and electrical bundles will be greater.

Cost

It is estimated that incorporation of this concept would increase the price of a twin-engine helicopter by less than $10,000.

Estimated Development Time

Time - A program to develop swing-down engine support arches could best be conducted by a prime helicopter manufacturer. It is estimated that a system could be designed, fabricated, and tested through the flight test stage with the expenditure of approximately 20,000 man-hours over a 12-month period.

Dollars - Completion of the program briefly discussed above will cost approximately $500,000.

Success Probability - High.

### Estimated Improvement Potential

While promising substantial improvements in engine replacement time and other worthwhile secondary benefits, the engine support arch concept involves substantial penalties in aircraft weight and cost. Further study would be needed to determine whether these are prohibitive.

## FLANGE-MOUNTED ENGINE

The purpose of this design study was to develop a concept for directly mounting an engine to the main transmission. Such mounting would have to allow close control of alignment and eliminate the need for an external shaft with misalignment compensating flexible couplings. No shaft alignment checks or adjustments would be necessary. Design goals included the use of a minimum number of fasteners and elimination of the requirement for ground support equipment other than a lifting sling.

### APPROACHES CONSIDERED

One design having potential evolved out of the flange-mounted engine design study. In the approach pursued, relatively light engines were bolted via their large-diameter intake housings directly to a main transmission.

### SELECTED CONCEPT - FLANGE-MOUNTED ENGINE

At the beginning of this study, it was recognized that an engine supported in cantilevered fashion would be subjected to different and, in some cases, more adverse dynamic and structural stresses. No attempt was made to analyze these stresses nor to suggest engine design modifications to cope with them. It was assumed that the engine manufacturing industry possessed the needed expertise for this kind of effort.

Acceptance of the above assumption permitted the scope of the current study to be narrowed to considerations of how to best mount the engine and how to best achieve shaft engagement.

The concept decided upon is shown in Figures 36 and 37. In this design, the engine has a heavy front frame which serves as the air inlet housing and bolts directly to the input housing of the main transmission. Concentricity is maintained via a male pilot protruding from the engine frame and a close-fitting female pilot machined into the transmission housing. Rotational indexing is accomplished by cone-bushings protruding from the engine frame which seat in countersunk bolt holes in the transmission housing. Four high-strength bolts with barrel nuts complete the attachment scheme.

Inherently, a front-flange-mounted engine installation involves an engine-to-transmission shaft coupling which is concealed. Engagement of this coupling, in the optimum design, should occur after concentricity of the two shafts is assured by initial engagement of the flange and boss pilots. To engage the

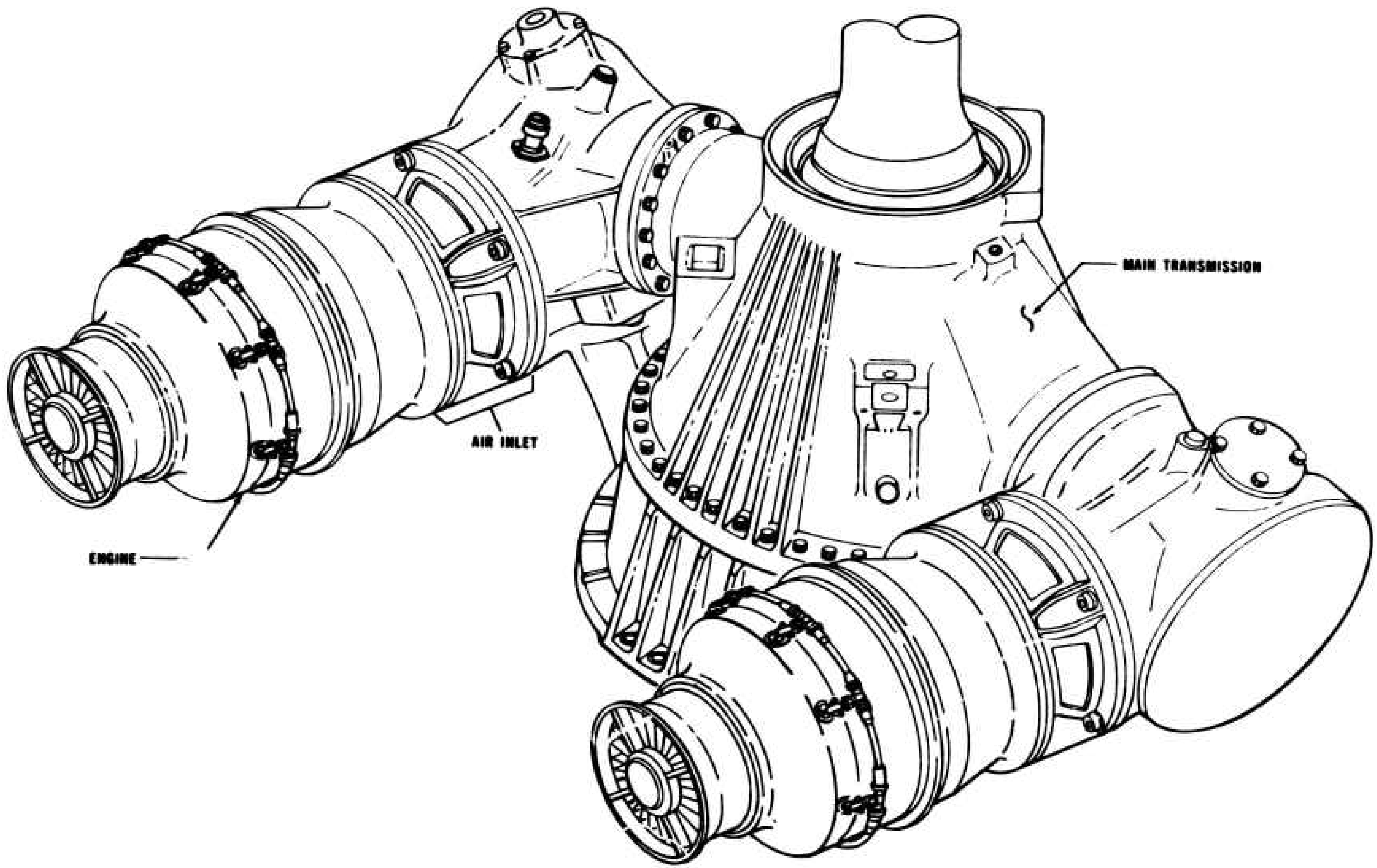


Figure 36. Flange-Mounted Engines.

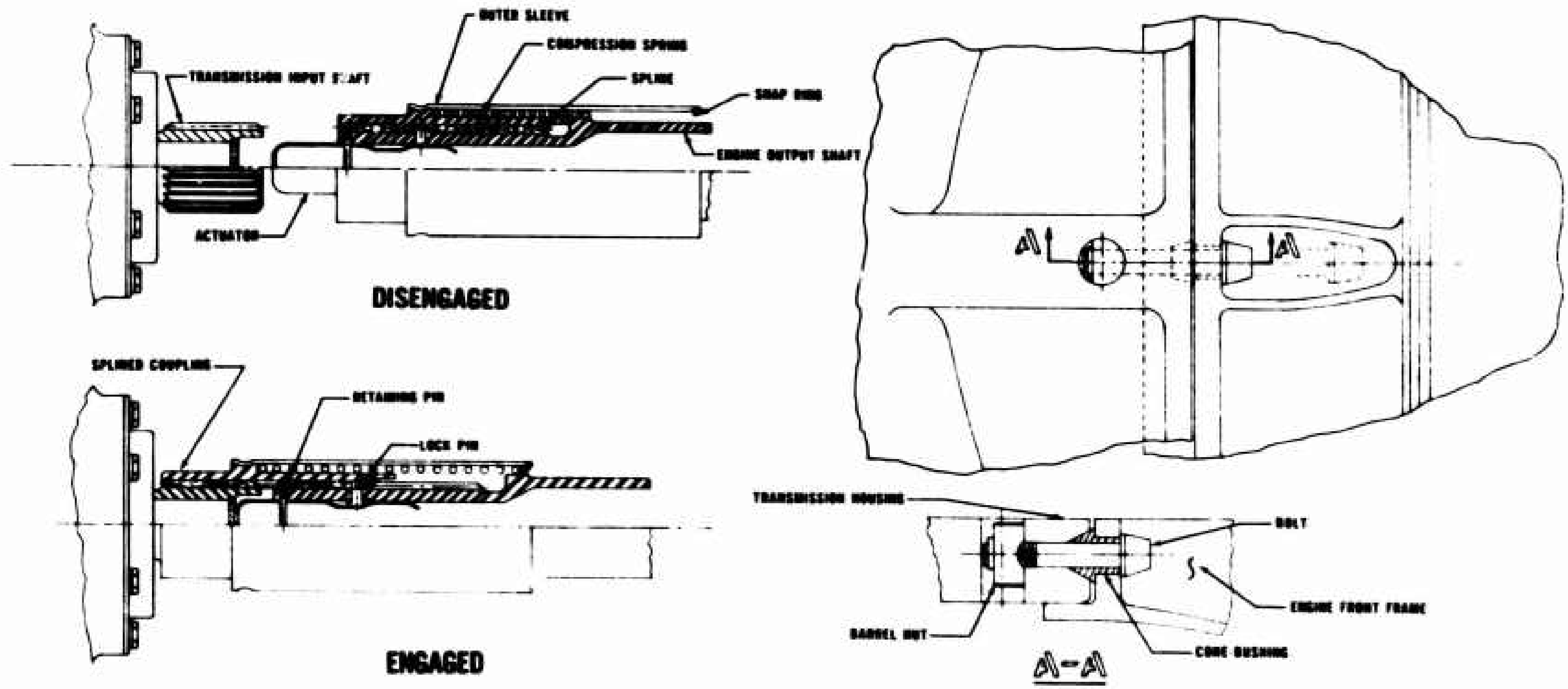


Figure 37. Details of Shaft Coupling and Bolted Joint for Flange-Mounted Engine Design.

two shafts prior to pilot engagement would expose them to the risk of severe bending stresses if the engine were to shift while hung from a sling.

Figure 37 depicts a design which assures sequential engagement, first of the concentricity maintaining pilots and then of the shaft coupling. Prior to mating the engine to the transmission, the shaft coupling is "cocked" by retracting its outer sleeve and extending the actuator tube full forward. This causes a lock pin to engage a detent in the sliding, splined coupling. During engine installation, the actuator contacts a plug in the transmission shaft and stops its forward movement while that of the engine output shaft continues. When the engine shaft has progressed to the point that the lock pin is in line with the recess in the actuator O.D., the pin falls into the recess. This allows the compressed spring under the outer sleeve to drive the sliding spline coupling into engagement with the transmission shaft.

## Benefits

The advantages of a flange-mounted engine are felt primarily in the areas of maintenance and reliability.

### Maintenance

Use of the flange-mounted engine concept completely eliminates the need for an external engine-to-transmission shaft. Typically, this shaft has two flexible couplings which consume a significant amount of maintenance time in terms of removals, repairs, inspections and lubrication. All this maintenance is eliminated with the proposed concept.

The flange-mounted engine uses a nonflexible connector shaft to drive the transmission. This connector requires precise engine alignment. However, in the new concept, proper alignment is a function of precisely machined mating flanges rather than adjustments made by a mechanic. In essence, flange-mounted engines are installed on a main transmission in much the same manner as a transmission driven accessory. Only four attach bolts with barrel nuts are used.

Having the engines and transmission grouped together compactly means that access to these components requires fewer or smaller pieces of cowling, which should reduce handling difficulties.

Reliability

Contemporary engine-to-transmission drive shafts and engine mount bearings are high failure rate items. Elimination of these items will have a positive effect on the aircraft's reliability.

## Penalties

As indicated earlier, no attempt was made in this study to assess the problems that an engine manufacturer might be faced with in developing a flange-mounted engine assembly. It was assumed that such an engine could be provided, and the only analysis made in this study was with regard to interface or installation problems.

Maintenance

Transmission replacement in the new concept will require removal of the engines rather than simply removal of engine-to-transmission drive shafts, a much more time-consuming task. Also, repair of transmission input seal leaks will necessitate removal of an engine.

Reliability

No provision has been made for wet lubrication (oil) of the short splined connector shaft. The shaft's wear rate may be unacceptably high unless this can be done.

Stress

The "cone-bushings" used at each attach bolt location will limit axial clamp-up of bolts or damage the light metal housing. Also, engine growth during warmup may excessively load these rigidly supported fasteners in a radial direction. More fasteners with lower radial stiffness would mitigate this problem. Nominal loads would be reacted through the clamp-up which would have more uniformly distributed loads.

To satisfy the requirements of vertical crash load conditions, it might be necessary to install a cradle beneath the engine near its center of gravity (unattached) to relieve the loads through the engine flange and transmission case and provide a 20G vertical crash capability.

Weight

The impact of this concept on aircraft weight is difficult to assess. In all probability, however, there will be a tolerable increase.

Cost

No estimate has been made of the effect on engine price that the flange-mounted concept would have. It is anticipated, however, that the price of a transmission for a twin-engine utility class helicopter would increase by about $2,000.

Estimated Development Cost

Time - No estimate has been made concerning the program to develop the engine required by this concept. However, a program to develop a mating transmission, carried through to flight test, using engines supplied by others, is estimated at 140,000 to 160,000 man-hours expended over a 42-month period.

Dollars - Cost of the program excluding development of the engines themselves is estimated to be in excess of 3 million dollars.

Success Probability - Moderate to high.

Estimated Improvement Potential

Development of the flange-mounted engine concept would incur costs far in excess of the potential savings in maintenance it promises. The added recurring cost of transmission, and perhaps the engines, might also be prohibitive. The concept is attractive only as part of an overall helicopter drive train development in which improvements in performance, weight, reliability, etc., were the dominant considerations.

## QUICK ATTACH/DETACH MECHANISM FOR MAIN ROTOR BLADE

The objective of this study was to develop a blade-to-hub attachment concept which would permit rapid blade removal and reinstallation. The goal was to devise a mechanism which would require only crude alignment for initial engagement and, by simply completing the engagement process, would progressively and automatically achieve final, precise alignment.

Other features sought included the use of a minimum number of retention devices which would be quick acting and not prone to binding or seizing during installation or removal. There was to be no additional reliance on special tools.

### APPROACHES CONSIDERED

Three approaches were considered in the study of main rotor blade replacement schemes:

1. Dual horizontal piano hinges.
2. Modified droop stops to allow additional droop for maintenance.
3. Conical receptacle in hub grip to receive extended blade spar.

#### Dual Horizontal Piano Hinges

In this concept, a machined forging serves as the root closure for main rotor blades. It is machined to produce what approximates two piano-type hinge halves which stretch from the leading edge to the trailing edge of the blade. The hinge pin holes are parallel to each other, perpendicular to the blade span, and separated from each other by a distance equal to the maximum chordal thickness of the blade. The main rotor hub has trunnions on which are mounted swiveling cuffs machined at their outboard ends in the same manner as the blade root closures.

Blade installation is accomplished by raising only the root end of the blade, engaging just the lower pair of hinge halves, and inserting a quick-release type hinge pin. The blade tip is then raised until engagement of the upper pair of hinges occurs. The second hinge pin is inserted, completing the installation procedure.

This concept involved a large weight penalty and moderate development risk. The only benefit appeared to be a small

decrease in installation/removal time. For this reason, the concept was abandoned.

Modified Droop Stops

This concept applies only to rotor systems which utilize centrifugal droop stops to limit blade droop when the rotor is static or in coastdown. In essence, the design creates a third position in the mechanism and permits droop even greater than the flight position.

The reasoning behind this approach is that a blade can be aligned and attached to a hub cuff more easily if its tip end can be grasped and maneuvered by a mechanic standing on the ground. This contention is open to disagreement, but even if valid, the degree of improvement in blade replacement time would be minimal. The concept was not considered to be worthy of further development.

SELECTED CONCEPT - CONICAL RECEPTACLE AND BAYONET

The selected concept for a main rotor blade quick attach/detach mechanism is illustrated in Figure 38. In this design the blade spar extends beyond the root closure and has fixed to it a bayonet type fitting. A mating conical receptacle is machined into the main rotor hub cuff (retention).

Installation is facilitated by the fact that initial engagement is between a small-diameter male pilot and a larger diameter female pilot. As the bayonet is pushed further into the cuff, radial and rotational alignment is automatically accomplished via the conical shape of the receptacle and an indexing pin/slot arrangement. Insertion of a quick-acting, expandable bushing pin completes the installation. A sectional view through the retention pin is shown in Figure 39.

Benefits

The benefits to be derived from a quick attach/detach mechanism for main rotor blades are in the area of improved maintenance.

Maintenance

Typically, much difficulty is experienced with current blade retention designs when attempting to align the retention pin holes in the blade with those in the grip, prior to installing the pin. This problem has been dramatically reduced in the proposed design. Due to the "bayonet" and "conical receptacle" features incorporated in the new concept, alignment for initial engagement is achieved easily. A small-diameter male pilot must simply

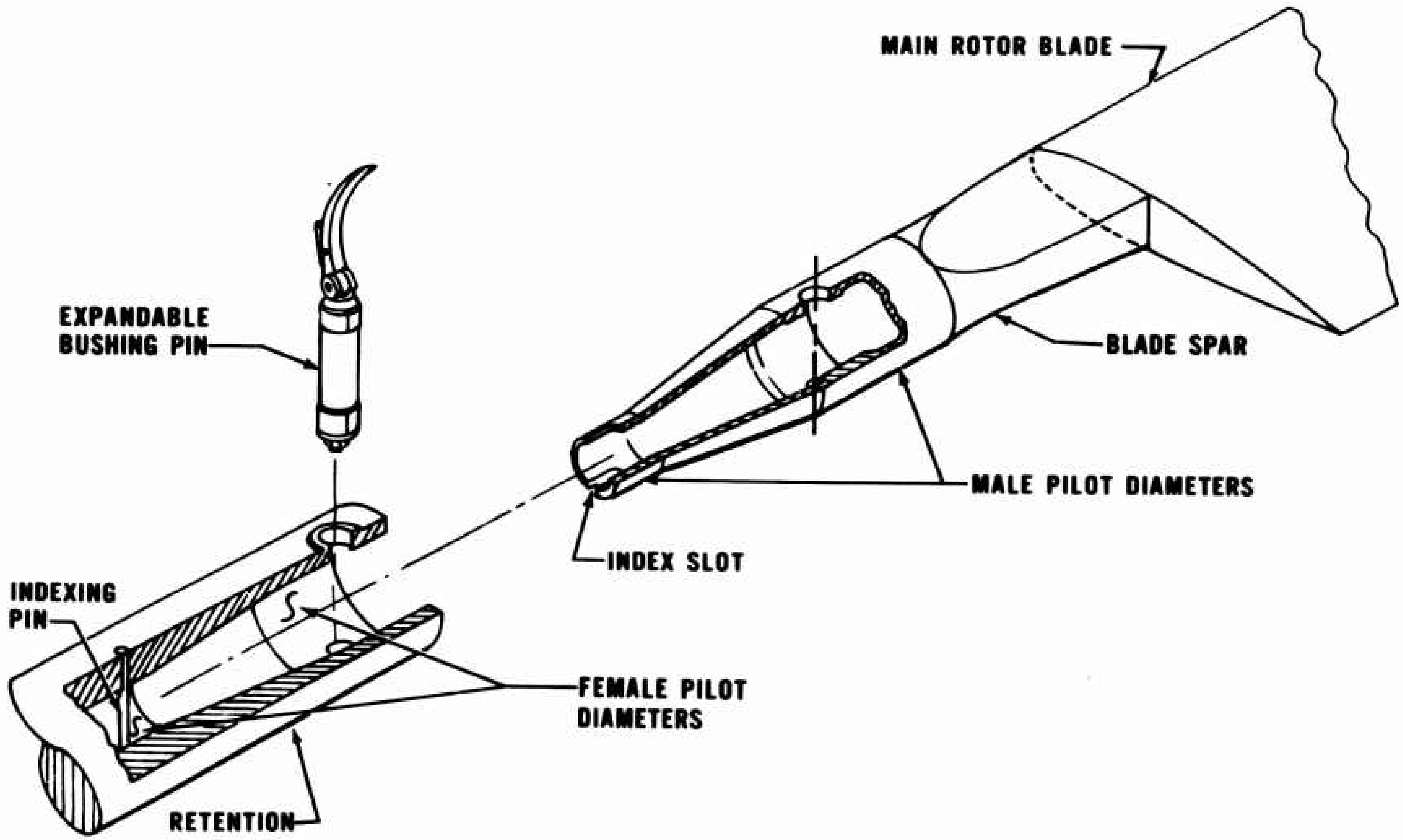


Figure 38. Quick Attach/Detach Mechanism for Main Rotor Blades.

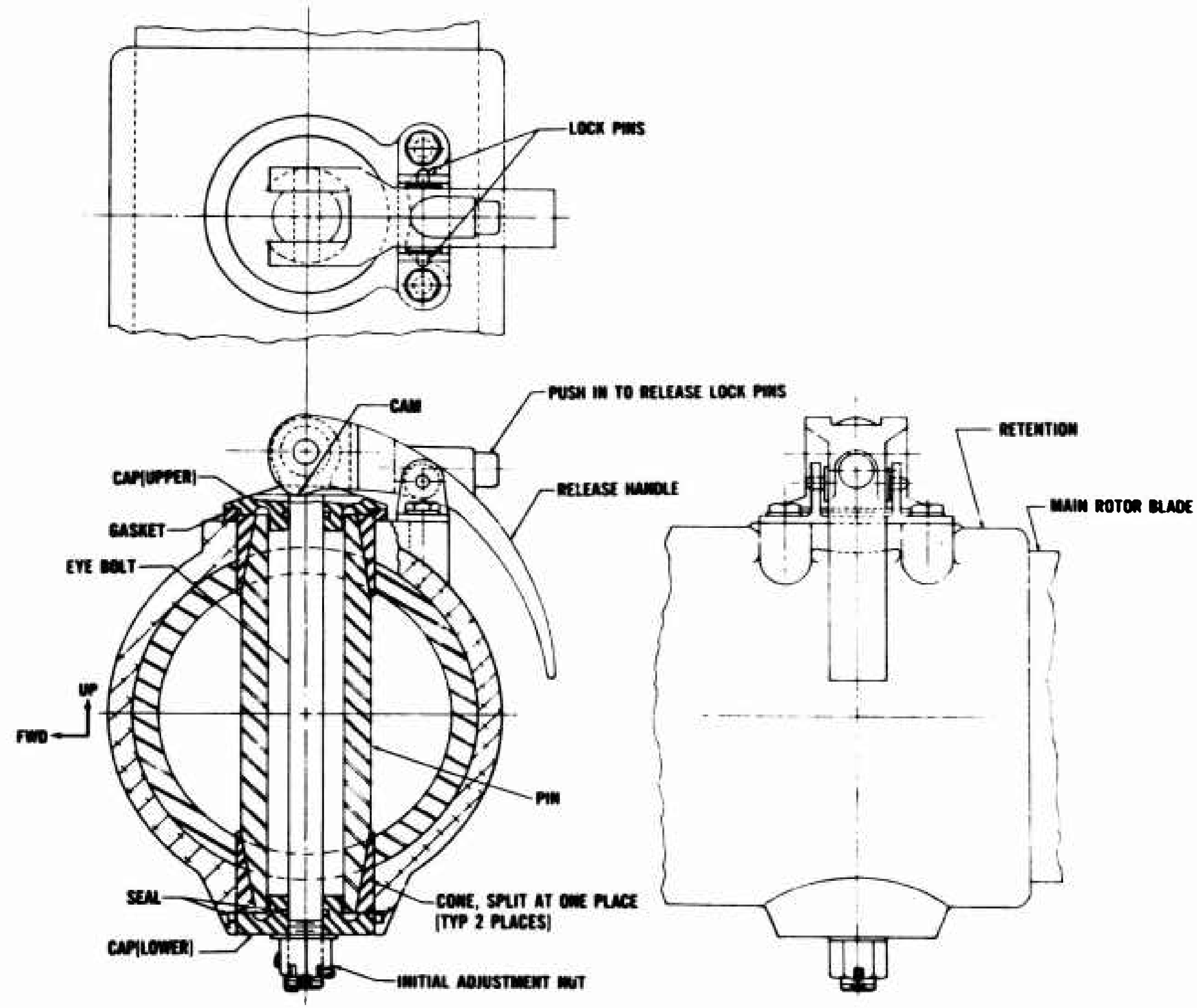


Figure 39. Details of Expandable Bushing Pin Used With Quick Attach/Detach Mechanism for Main Rotor Blades.

be guided into a much larger diameter female pilot. Final alignment occurs automatically as the blade is pushed into full engagement with the grip.

A single, quick-acting, expandable bushing pin is used to retain the blade to the grip. There is no requirement for lockwire. The concept eliminates the need for any special tools except perhaps for slings to lift the heavier blades. Common hand tools are also not required except for initial adjustment of the nut at the bottom of the retention pin.

## Penalties

Minor penalties exist in several areas.

### Maintenance

The increase in blade length due to the extended spar will increase handling difficulty somewhat. Shipping containers will need to be larger.

### Reliability

Some thought should be given to incorporating a device into the retention pin mechanism which would ensure that the split, tapered bushings contract when tension in the drawbar is released. Taper seats can be difficult to separate when they are pulled together under high axial loads and then fret in a fatigue environment. No provisions have been made for sealing the "bayonet" and "conical" receptacles at the large diameter pilot. This may lead to a corrosion problem.

### Stress

The position of the split line in the retention pin bushings should be selected and indexed in the mechanism. It would be unwise to have the split on a spanwise line, since it would be on the centrifugal force bearing surfaces of the joint. The best probable location for the split line would be on a line 90$^{o}$ to the blade span direction. Although not shown in the sketches, high press fit bushings should be used in the pinhole in both the spar and grip members. This will provide needed fatigue protection to the joint.

The plane of the retention pinhole snould be carefully selected to be on a neutral axis of the least vibratory moment (edgewise or flatwise) depending on the type of rotor system to which it is being applied. Lastly, there

is reason to doubt that sufficient mechanical advantage can be generated in a simple cam action to create an axial force large enough to adequately clamp the split bushings to the grip and blade bushings.

Weight

This concept could add 5 to 8 pounds for each blade used on the helicopter.

Aerodynamics

The proposed design will have only a minor effect on overall aircraft performance. Hovering capability and low-speed performance such as climb and endurance will be unaffected. It is estimated that the new design will increase the total parasite drag area of the helicopter by less than 5 percent, assuming a UH-1 type helicopter. This drag change, which increases the power required in level flight, will impact the high-speed performance and range capability by 1 to 2 percent.

Cost

There should be little or no increase in recurring cost per helicopter due to incorporation of this design concept.

Estimated Development Cost

Time - Development of the proposed method of blade attachment is not possible unless accomplished as part of a comprehensive rotor development program. Such a program would produce new designs for blades, hub and rotor controls. It is estimated that an expenditure of 130,000 man-hours over a 4-year period would be required.

Dollars - Development of a new rotor system incorporating the proposed method of blade attachment would cost approximately 3 million dollars.

Success Probability - Moderate to high.

Estimated Improvement Potential

This concept cannot be considered as an independent development apart from the rotor in which it will be incorporated. It is considered to offer a significant improvement potential if it can be successfully integrated with a future rotor system, however.

## SPLIT SWASHPLATE

The objective of this study was to develop a concept which would permit replacement of the swashplate without first having to remove the main rotor and the rotor controls. In view of the complexity of current design swashplates, an important restraint imposed on the new concept was that the number of small, loose parts be minimized. The optimum design should group parts into easily handled subassemblies. Elimination of shimming to adjust stack-up pinch or bearing preload was established as another design goal. Lastly, installation should be accomplished using nothing more than mechanic's standard hand tools.

### APPROACHES CONSIDERED

Two basic approaches were considered:

1. Split swashplate with metal uniball for plane changes due to cyclic inputs.

2. Split swashplate with elastomeric bearing for plane changes due to cyclic inputs.

The two concepts involve swashplates which slide up and down the transmission output shaft (or mast) to provide collective control input to a four-bladed main rotor. The description of each concept will begin with the innermost member of the swashplate assembly (item in contact with the mast) and work outward.

### Split Swashplate with Uniball

In the first concept, plane changes for cyclic input are made possible by a large-diameter uniball at the core of the swashplate. The uniball, which has an I.D. to match the mast O.D., is split axially and placed around the mast. A bronze spherical seat surrounds the ball and is itself captured in the rotating swashplate ring by a bolted retaining ring. The spherical seat is split along its axis to permit assembly onto the uniball via a radial direction. It is also split in a plane perpendicular to its axis to provide adjustment of the "pinch" it exerts on the uniball. This adjustment is accomplished by shimming.

The rotating swashplate ring has four trunnions to which connect pitch change links leading to blade pitch horns. The rotating swashplate ring is made in two pieces with the split occurring in a vertical plane midway between two pairs of trunnions. Two expandable bushing pins join the halves.

Outboard of the rotating swashplate ring is located the nonrotating swashplate ring which incorporates trunnions for attachment of push-pull control rods. The nonrotating ring is split and joined in the same manner as the rotating ring described above.

Between the rotating and nonrotating swashplate rings is located a large-diameter, double-row ball bearing which is also split axially. The bearing is encased in a molded nylon housing which facilitates handling and serves additionaly as a seal during operation. Bearing preload is established during manufacture via custom-ground spacers, also encased in the nylon housing. The inner and outer races of the bearing are respectively secured to the rotating and nonrotating swashplate rings by shimmed retaining rings. The compressive load, or "pinch", created by the retaining rings is not carried by the bearing's nylon housing but by a series of metal buttons molded into the housing.

Two significant disadvantages discouraged further development of this design concept:

1. The uniball and spherical seat are in six pieces excluding shims, which are also split. This multiplicity of parts would make assembly and pinch adjustment extremely difficult.

2. The molded nylon housing for the double-row ball bearing presented a great development risk.

## SELECTED CONCEPT - SPLIT SWASHPLATE WITH ELASTOMERIC BEARING FOR PLANE CHANGES

Figures 40 and 41 illustrate the selected concept. This design is similar to the one described earlier except for the differences presented below.

An elastomeric bearing, split axially into two halves, is used in lieu of a six-piece uniball and spherical socket. This novel approach for making swashplate plane changes dramatically eases the mechanic's assembly task. The ball bearing situated between the rotating and nonrotating swashplate rings is split axially as was the bearing in the first design. This bearing, however, does away with the molded nylon housing and uses instead frangible plastic screws to prevent relative rotation between inner and outer race halves. If allowed to occur, this rotation might result in loss of balls, grease, etc., during handling. These plastic screws are never removed from the bearing. Upon initial turn-up, they fracture, in a manner

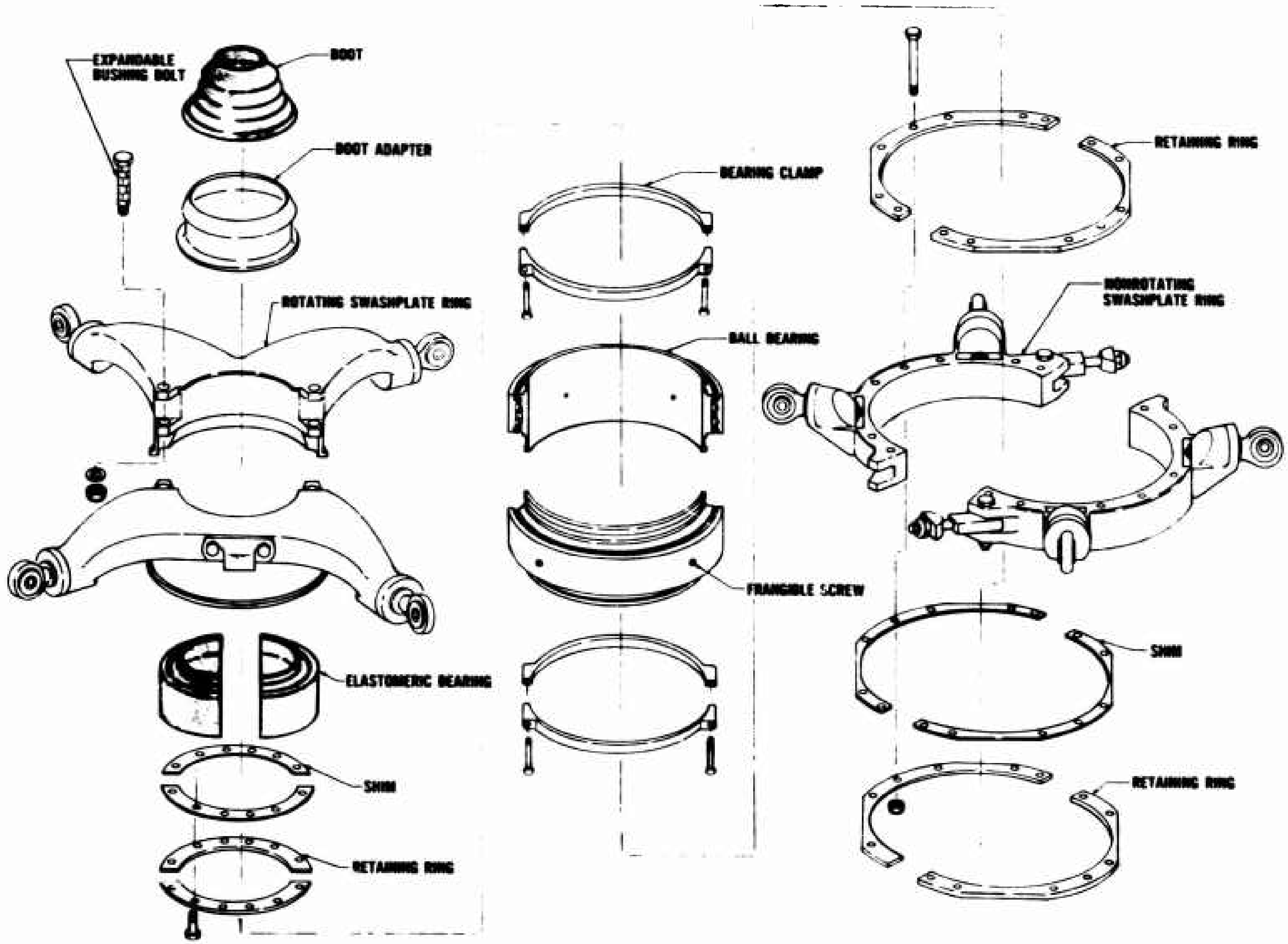


Figure 40. Exploded Isometric View of Split Swashplate.

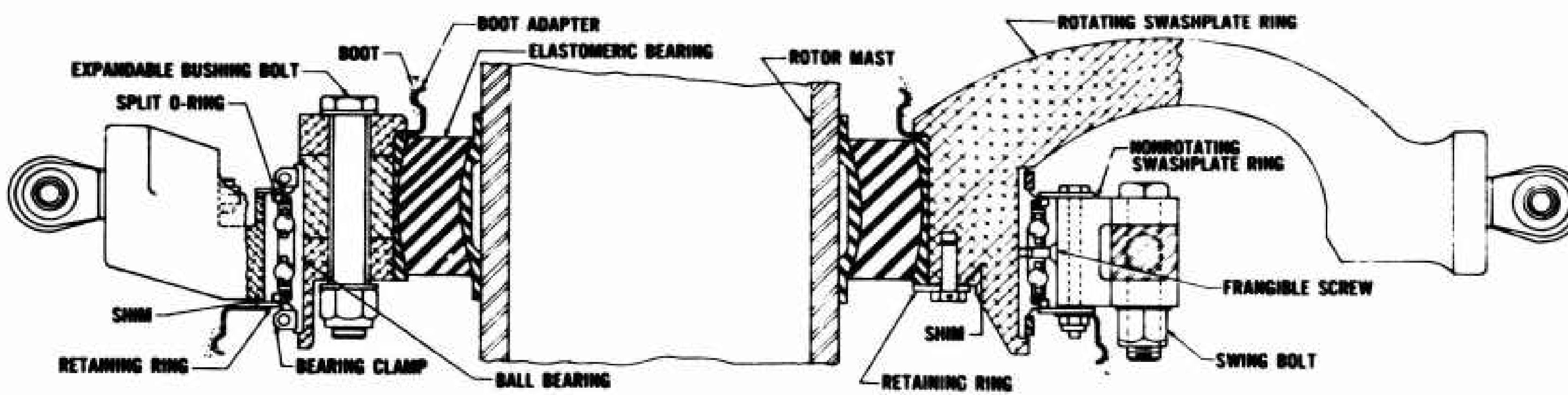


Figure 41. Sectional View of Split Swashplate.

that poses no threat to proper operation of the bearing.

Installation of the bearing on the rotating swashplate ring is made easier through the use of two pairs of semicircular clamps in lieu of a split retaining ring and shims. The bearing design includes easily replaceable O-ring seals.

Lastly, the selected concept differs from the original concept in that it utilizes "swing-away" bolt mechanisms in lieu of expandable bushing pins to join the nonrotating swashplate ring halves together.

## Benefits

Benefits from this concept are realized in the areas of maintenance and reliability.

### Maintenance

The most significant advantage afforded by the split swashplate concept is the ability to replace a swashplate without first having to remove rotor blades and the rotor hub. Also, the split swashplate design permits "on aircraft" replacements of failed bearings as opposed to the current practice of replacing entire swashplate assemblies. The ability to gain access to detail bearings enables inspectors to easily ascertain their internal condition.

### Reliability

There will be fewer removals of main rotors. This will undoubtedly result in fewer occurrences of maintenance-induced damage to rotor blades, hub, and controls.

## Penalties

Penalties associated with the split swashplate concept are numerous and appear to outweigh the potential benefits substantially.

### Maintenance

Many loose parts must be handled, and the intricate assembly procedure would require the skill of a highly trained mechanic. Both major bearings, the elastomeric bearing and the double-row ball bearing, require shimming. While installing the ball bearing, there is a high probability of losing some of the grease, or perhaps contaminating it.

Reliability

The splits in the races of the double row ball bearing aggravate the load distribution problem and reduce bearing life. Although the shear angles through the elastomeric bearing are probably low, the lack of continuity through the elastomer (splits) will reduce the bearing's durability. When the frangible screws in the ball bearing fracture, debris may be produced which will tend to jam the ball cage, adversely affecting bearing performance. Lastly, the probability of maintenance error during assembly of the swashplate is high due to the complexity of its design.

Stress

The metal hub which forms the I.D. of the elastomeric bearing is subjected to moment loading. This could cause wear on the rotor shaft, resulting in dangerous stress concentrations on the shaft. The elastomeric spring rate introduces additional stabilizing forces in the control system, although these are not large.

The two halves of the rotating swashplate ring are joined by expandable bushing pins through clevis arrangements. Any axial looseness in the clevis joint due to machining tolerances will result in fretting on the bolt and in the clevis holes. This will decrease the fatigue strength of the joint. Too much responsibility is given to the single fastener used at each joint.

The split-race ball bearing is being used in a typically lightly loaded application. However, load distribution due to hard spots is crucial. The rotating and non-rotating swashplate rings provide several hard points inherent in the split configuration. Load distribution becomes an increasing problem if the clevis joints loosen.

The ball bearing is stabilized radially by two clamps on its inner race. These clamps will suffer cyclic loading and are subject to fretting and loosening. The ball bearing should be preloaded to insure tractive rolling and positive driving of the cage. This should reduce the tendency of cage ends to overlap and jam, but will reduce the bearing's service life.

Weight

A split configuration swashplate for a utility class helicopter will weigh approximately 2 or 3 pounds more than a conventional swashplate.

## Cost

The increase in cost of a split swashplate versus a conventional swashplate is estimated to be less than $3,000.

## Estimated Development Cost

Time - A program to develop a split swashplate could best be conducted by a prime helicopter manufacturer. It is estimated that an installation can be designed, fabricated and tested with the expenditure of approximately 20,000 man-hours over a 24-month period.

Dollars - The estimated cost of a split swashplate development program is under $500,000.

Success Probability - Low to moderate.

## Estimated Improvement Potential

In attaining the original objective of this study, i.e., designing a swashplate which could be removed independently of other components, disadvantages of major proportion were introduced. From the work thus far accomplished, these appear too numerous and too severe to advocate its further pursuit.

## KEYED HYDRAULIC QUICK DISCONNECTS

The objective of this study was to develop a concept for keying mating halves of quick disconnects to preclude cross connection of lines.

### APPROACHES CONSIDERED

Two basically different approaches were considered:

1. Redesigned quick disconnects with integral keys.

2. Snap-on plastic jackets for use on currently available quick disconnects.

### Quick Disconnects With Integral Keys

This approach merely expanded the design of standard quick disconnects to include a keying mechanism. Several different key shapes (or multiple arrangements of the same shape) are provided for each line size to be served. The only disadvantage with this approach is that so many additional couplings with different part numbers would need to be stocked. The Army's investment in spare couplings would increase several times over what it now is. A second design approach, discussed in the following paragraphs, requires a much smaller investment in spares assets.

### SELECTED CONCEPT - PLASTIC SNAP-ON COLLARS FOR KEYING HYDRAULIC QUICK DISCONNECTS

Figure 42 depicts an economical, lightweight method of keying quick-disconnect couplings to preclude cross connection of lines. The concept employs keyed, plastic collars which snap onto mating halves of a conventional coupling. Both collars are split axially to permit them to expand temporarily while being assembled. Assembly must take place prior to connection of lines or hoses. Snap rings are utilized to retain the collars to the respective coupling halves. Several different key arrangements are provided for each line size. To aid the mechanic in distinguishing between arrangements, the collars are color coded.

### Benefits

The purpose of this device is to prevent improper maintenance; it has value only if the rate of human error is expected to be significant.

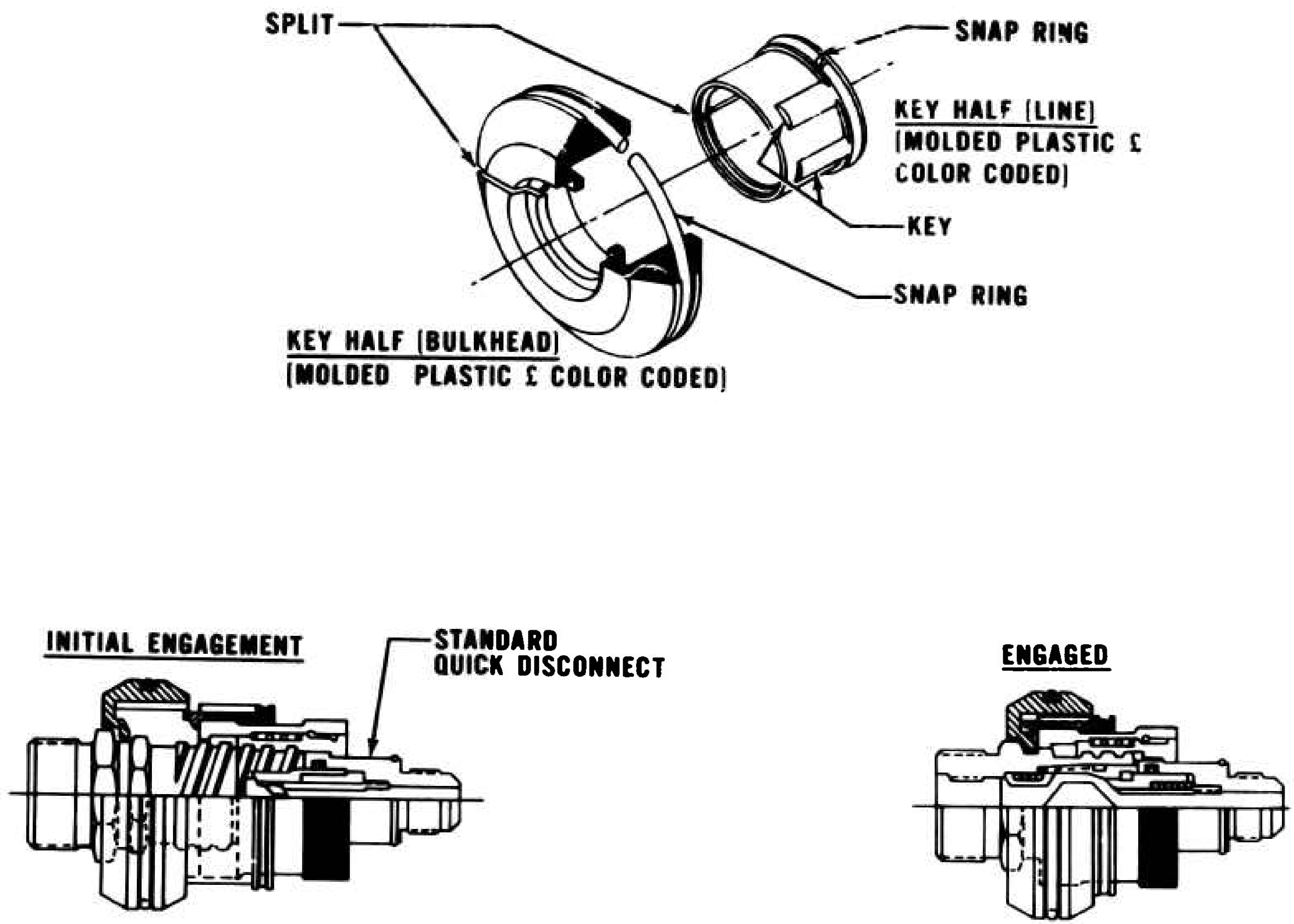


Figure 42. Keyed Collars for Fluid Line Quick-Disconnect Couplings.

### Maintenance

Whenever two or more lines of the same size have quick-disconnect couplings located in proximity to one another, cross connection during maintenance is possible. Should this occur, the error is not likely to be noticed until extensive damage is done to components in the system. The proposed snap-on collars for quick-disconnect couplings make cross connection impossible. To aid the mechanic in quickly determining which two coupling halves are mates, the collars are color coded.

### Reliability

Prevention of damage to only a few expensive components, with the attendant high cost in repair man-hours, could make the proposed device very attractive.

## Penalties

Few penalties of much consequence are associated with the keyed plastic collar concept.

### Maintenance

Addition of the collars makes standard couplings more bulky. They also reduce the area available for the mechanic's hands to grip during the engagement/disengagement process.

### Reliability

Failures of the plastic collars themselves will detract from the helicopter's overall reliability. The feature most vulnerable to damage appears to be the fragile plastic shoulders which engage grooves in the metal coupling to lock the two items together axially.

### Cost

It is estimated that the proposed collars will cost less than $5.00 per set.

## Estimated Development Cost

Time - A program to develop plastic snap-on collars for keying quick-disconnect couplings could best be conducted by a manufacturer of fluid line fittings. It is estimated that a program carried through to environmental testing

would require 2,000 man-hours expended over a 10-month period.

Dollars - A program of the size noted above would cost approximately $50,000.

Success Probability - High.

Estimated Improvement Potential

Several factors recommend this concept for further development. The costs, both developmental and recurring, are low. The concept has a high probability of success and would be retrofitted to some present installations.

# QUICK ATTACH/DETACH MOUNT FOR ENGINE OR TRANSMISSION DRIVEN ACCESSORIES

The objective of this design study was to develop a concept for accessory mounting which would allow speedy replacement of the accessory. Constraints imposed on the concept were that it be universally applicable without regard to type of accessory and that a miminum number of quick-acting fasteners be utilized. One important feature sought was the capability to support the accessory after only initial engagement and prior to final clamp-up. The intent was to relieve the mechanic from manually supporting the accessory while he was involved in removing or securing it.

## APPROACHES CONSIDERED

Eleven design variations were considered. These fell generally into six generic groups:

1. Modified studs, through-flange arrangements.

2. Tension latches.

3. Interrupted, interlocking flanges.

4. Tubular supporting housing.

5. Bolts with eccentric shanks acting radially against flange of accessory.

6. Collet mechanisms.

### Modified Studs Through Flange

Two concepts of this type were conceived. The first placed several studs outside the major diameter of the accessory flange and utilized a clamp under each stud nut to secure the accessory to the gearbox mounting boss. The second variation passed several unique studs through the accessory flange. Permanently installed on each stud was a threaded nut, a tapered collar and a split ring. The holes in the flange were large enough to allow all of this hardware to pass through. Tightening the nut forced the tapered collar into the split ring, thereby expanding the ring into a locking recess in the stud hole in the accessory flange.

A cursory analysis of these designs revealed several important disadvantages which prompted their abandonment. Most significantly, many slow-acting fasteners had to be manipulated.

Also, the clamping force generated by these fasteners would have been less than with most other designs. These concepts were heavier and required studs on larger diameter bolt circles, which requires more mounting area on the driving gearbox.

Tension Latches

Two concepts of this type were considered. The first involved several individual, overcenter tension latches mounted on the accessory. The second design took the tension straps from the individual latches, increased their length, and pinned them to a hub at the rear of the accessory. A single jackscrew through the center of the hub reacted against the back end of the accessory, creating tension in all the straps after they had been hooked to a ring on the gearbox mounting boss.

Neither of the above designs showed enough promise to warrant further development. A major fault common to both was that only low clamping forces could be developed. Also, the need for much side clearance prevented close grouping of accessories on the driving gearbox. In the case of the hub-with-jackscrew design, a very bulky mechanism became a loose item which had to be stowed when the accessory was not installed.

Interrupted, Interlocking Flanges

Two designs of this type were considered. Basically, the concept involved an accessory with a flange interrupted in three places. The mounting socket on the driving gearbox had a flange machined in a similar fashion. Installation was accomplished by engaging the two flanges and rotating the accessory 60 degrees so that the flanges interlocked.

One design maintained the interlock condition by using a large-diameter spanner nut. In the second design, the mating flange surfaces were contoured to create a detent. Locking screws acting against springs held the accessory in the detent position.

These designs had several serious drawbacks which encouraged their abandonment. Most importantly there appeared to be very little improvement in replacement time. Also, much space was required to turn the spanner wrench or to tighten the locking screws. This would effectively reduce the density of accessories mounted on the driving gearbox. Both designs required relatively expensive machining operations, and the design utilizing springs to maintain lugs in the detent position was considered to be a high development risk. The mounting stiffness of both designs was low.

Tubular Support Housing

Two designs were considered which involved inserting the accessory into a tubular housing on the driving gearbox. This concept had the advantage of relieving the mechanic of the need to manually support the accessory while he went about securing it in place.

The first design utilized a spring steel band on the accessory which snapped into a circumferential groove in the I.D. of the support housing, thereby retaining the accessory. The second design used a cap which slipped over the back end of the accessory and hooked into the O.D. of the tubular support housing. A single jackscrew through the center of the cap acted against the back of the accessory, thus clamping it against the gearbox boss. When used for electrical generators, the cap-with-jackscrew design used integral quick-disconnects for electrical and cooling air lines.

These devices offered several desirable features. Overall, however, the advantages were outweighed by the disadvantages and the ideas were eliminated from further consideration. The disadvantages included high development risks, large weight and cost penalties, and creation of moisture/corrosion traps. The design utilizing a spring steel band could generate only very light clamping forces and needed much space in order to swing a spanner wrench. The cap-with-jackscrew devices presented the problem of stowing a loose and very bulky item when the accessory was not installed.

Bolts With Eccentric Shanks

This design attempted to capitalize on the camming effect capable of being produced by bolts with eccentric diameters. A special adapter plate on the gearbox held two bolts parallel to each other, one above the accessory and one below the accessory, with the axis of the bolts perpendicular to the axis of the accessory. To install the accessory, both bolts are rotated so that their eccentric midsections move to provide clearance for passage of the accessory flange. After the accessory is seated in its pilot hole, the bolts are rotated in the opposite direction until they contact the accessory flange and clamp it against the driving gearbox boss.

This idea was abandoned when layouts indicated that the amount of eccentricity required for flange clearance was so great that only small clamp-up forces could be generated when the bolt was rotated against the flange.

## Collet Mechanisms

Two attempts were made to adapt the collet principle to the task of mounting accessories. The first design utilized a cyclindrical accessory without the usual mounting flange, but had instead a circumferential groove on its O.D. near the end to be secured to the gearbox boss. Bolted to the gearbox was a cylindrical receptacle. In the I.D. of the receptacle was a circumferential ridge which matched the contour of the groove on the accessory. The wall of the receptacle had several axial slits which permitted the inside diameter to be reduced when a compressive force was applied to the outside diameter. When this diameter reduction occurred with an accessory installed, the ridge and groove discussed above were locked in engagement and the accessory was thereby secured. Design number one utilized a tapered collar, drawn over the O.D. of the receptacle by three draw bolts, to shrink the diameter of the receptacle (or collet).

This design offered some advantages not found in earlier designs. However, among the disadvantages was an unacceptable one. The three collar draw bolts had to be sequentially operated in small turn increments in order that the collar not "cock" on the collet. Also, jam nuts were used to lock the draw bolts, and much space for wrench swing was required on the sides of the accessory.

The second design employing the collet principle improved upon the first and was selected for further study. This concept is described below.

## SELECTED CONCEPT - COLLET WITH BAND CLAMP

This design utilizes a collet-type receptacle to mount a flangeless, cylindrical accessory. Figure 43 presents an artist's conception of a typical installation. Improvements incorporated in this design over the last are discussed below.

In its relaxed state, the I.D. of the collet matches the O.D. of the accessory. During installation, the tapered leading edge of the accessory penetrates the collet and spreads the collet fingers. The collet remains expanded as penetration continues until the ridge in the collet drops into the groove on the accessory O.D. At this point, the accessory needs no manual support, and the mechanic's hands are free to lock the collet and accessory in engagement. Locking is accomplished by a quick-acting band clamp, quick-acting in the sense that the nut on the tension bolt is only loosened and tightened, but never removed.

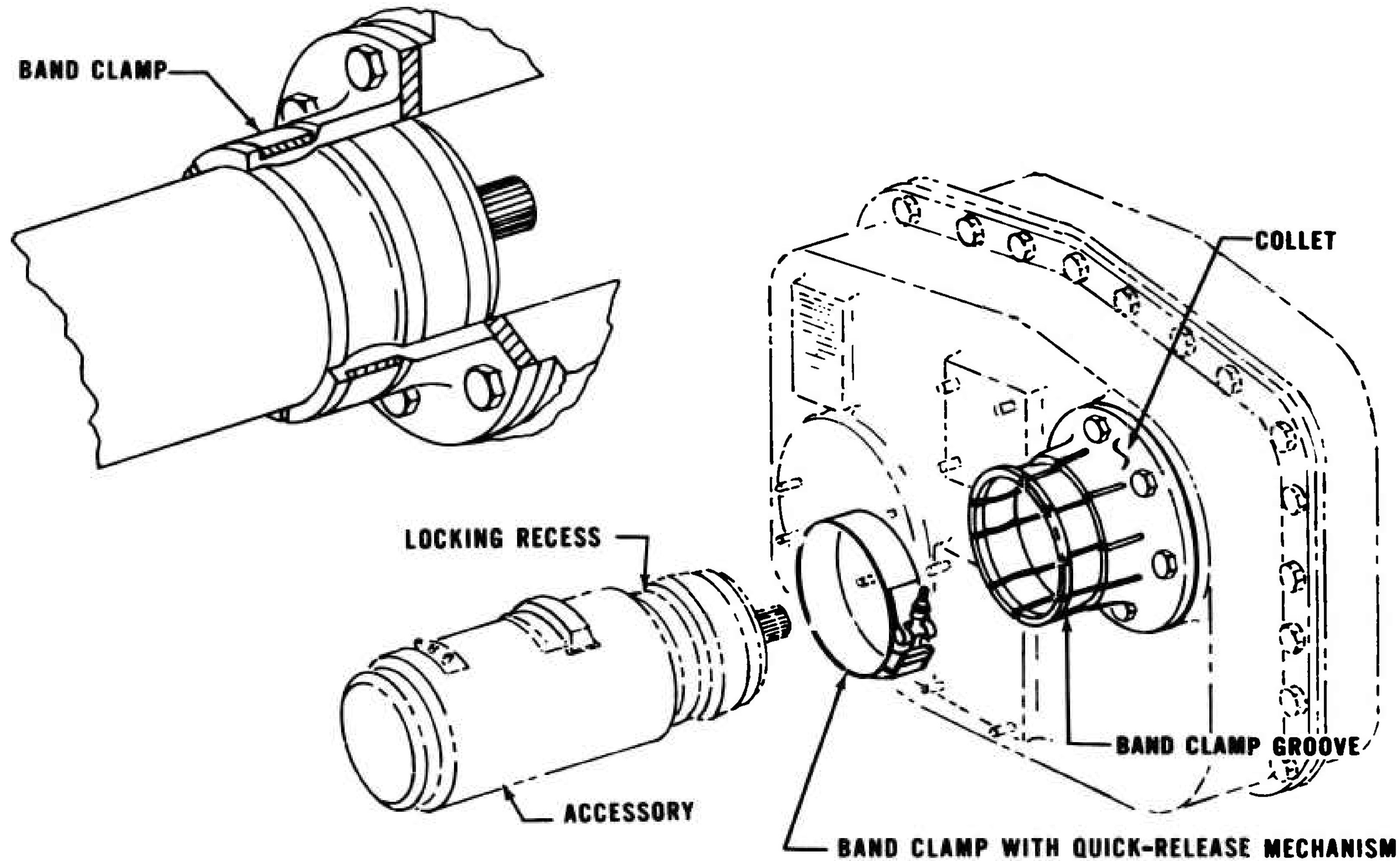


Figure 43. Quick Attach/Detach Mount for Accessories.

## Benefits

As intended at the outset, this new concept produced benefits primarily in the area of maintenance.

### Maintenance

The detent-type fit between the collet and the accessory eliminates the currently prevailing requirement to manually support the accessory while it is being secured. This is a noteworthy improvement, especially where heavy accessories in uncomfortable locations are involved.

Typically, several nut-on-studs have been replaced by a band strap with a single threaded locking mechanism. The strap can easily be positioned to provide the best possible access to the locking mechanism. No special tools are required.

## Penalties

Few penalties are associated with this concept. Some important items of concern were expressed during a cursory stress analysis of the proposed design, however.

### Maintenance

There are no significant disadvantages from the standpoint of maintenance. The only potential problem presented by the proposed design is that, when unlatched, the band becomes a loose item subject to loss.

### Stress

It is doubtful that friction alone will provide a satisfactory reaction to torque which might be experienced by the accessory housing. A preferred design would incorporate keys or pins to react the torque. Another improvement deemed necessary is creation of a shear pilot at the interface between the accessory and the case. This would provide additional support and assure concentricity of the shafts.

### Weight

A weight increase will result from adoption of this concept. It will vary from 1 to 4 pounds depending on the size and weight of the accessory it is intended to carry.

Cost

It is estimated that the proposed collet type adapter for mounting accessories will cost about $100 more per accessory than the conventional method of mounting.

Estimated Development Cost

Time - A development program could best be conducted by a manufacturer of accessories such as electrical generators. It is estimated that a mount system can be developed and tested with the expenditure of 8,500 man-hours over an 18-month period.

Dollars - Cost of a development program would be approximately $200,000.

Success Probability - High.

Estimated Improvement Potential

This concept, because of its wide potential applicability and few apparent penalties, is considered worthy of further pursuit. The expected improvements in maintenance appear to justify the modest investment development would require.

## MODULARIZED OIL PUMP

The concept of a modularized oil pump was not scheduled for development in Phase II of this study, nor were oil pumps included in the list of components analyzed in Phase I. However, the idea of a modularized oil pump emerged. This concept was developed more fully and is reported upon in the following paragraphs.

Figure 44 presents an artist's conception of an oil pump which is designed in two modules: a fluid interface section and a mechanical pump section.

The fluid interface section is by far the least complex of the two sections and is presumed to have very high reliability. It is reasonable, therefore, to attach the fluid interface module to the driving gearbox in a semipermanent manner. All lines from aircraft-mounted components such as reservoirs, coolers, etc., connect to this section and are seldom disconnected. Passages in the interface housing carry fluid to integral quick disconnects which automatically engage inlet and outlet ports in the mechanical pump section as the pump is secured to the interface section. The quick disconnects contain automatic shutoffs to prevent loss of oil when the pump section is removed.

The pump module contains all the mechanical parts which normally comprise an oil pump. This section is designed for extremely easy replacement; because of the two modules, it will have the highest removal rate. Installation is accomplished by inserting a cylindrical pilot section into the bore in the fluid interface module. When fully inserted, drive shaft splines and fluid couplings are engaged. A "V" band clamp secures the pump module to the fluid interface module.

### Benefits

Reduced man-hours required for pump replacement and fewer incidents of maintenance-induced damage are the most significant benefits of the modularized oil pump concept.

#### Maintenance

Removal of the mechanically driven oil pump requires nothing more than undoing a "V" band clamp. There are no fluid lines to disconnect, nor any spilled fluid to collect or wipe up.

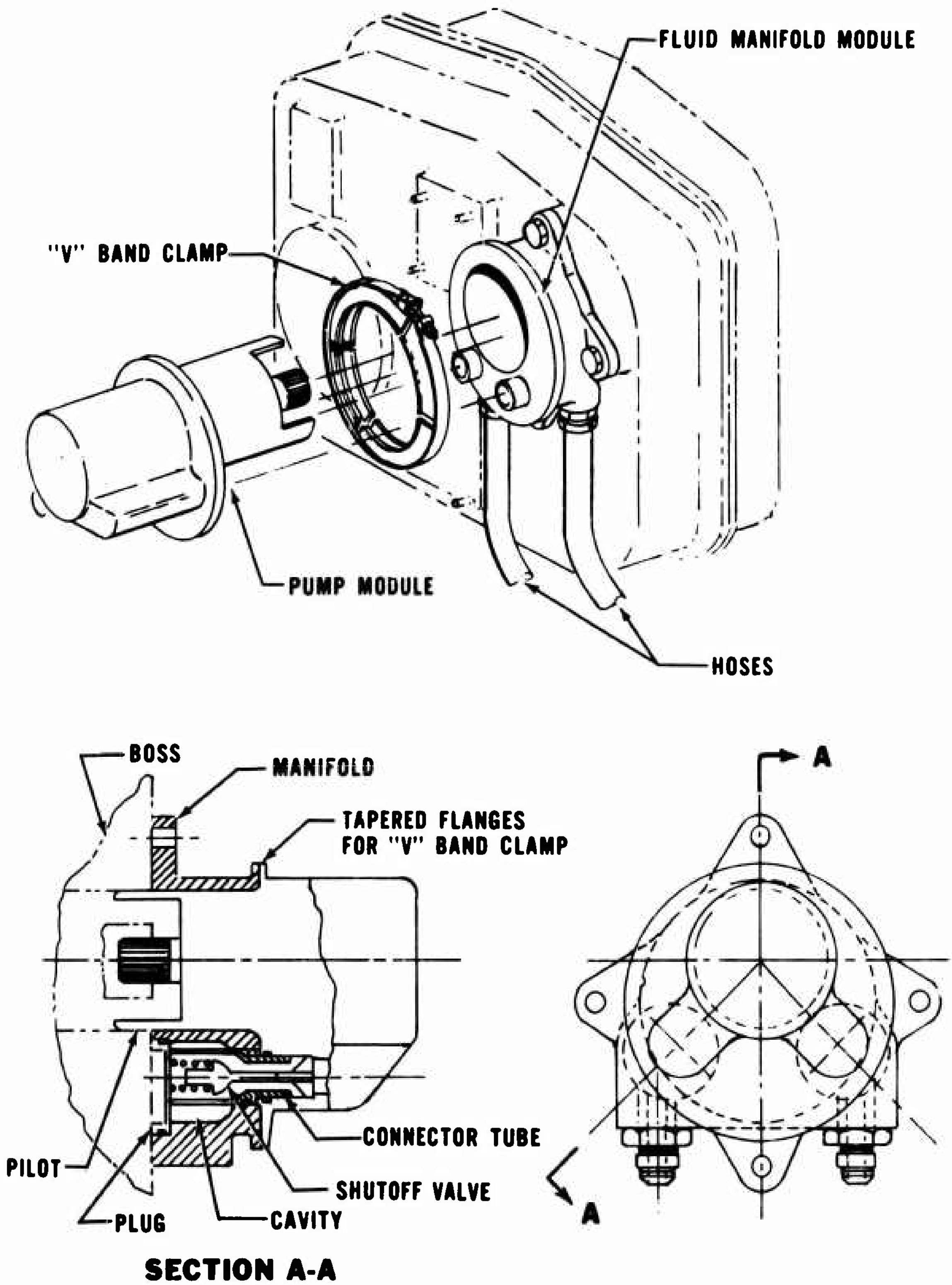


Figure 44. Modularized Oil Pump.

### Reliability

There will be fewer instances of cross-connected lines and fewer cases of cross-threaded line fittings. There will be considerably less opportunity to inadvertently bend lines beyond design tolerance. The overall effect on aircraft reliability will be positive.

## Penalties

Weight and cost considerations suffer most in a trade-off analysis of modularized oil pumps.

### Maintenance

A large amount of space is required behind the pump module to allow disengagement of its long cylindrical pilot from the fluid interface module. This may not, however, be a disadvantage in all installations.

### Reliability

The quick disconnect and automatic shutoff features of the fluid interface module will add somewhat to the unreliability of the installation.

### Stress

Torsion should be reacted by dowels or keys rather than quick-disconnect connector tubes.

### Weight

Incorporation of the proposed concept will add approximately 3 to 4 pounds to the weight of the pump.

### Cost

The increase in cost of the pump would be approximately $500.

## Estimated Development Program

Time - A program to develop a modularized oil pump could best be conducted by a manufacturer of lubrication or hydraulic pumps. It is estimated that a program, including bench endurance testing, would require 4,000 man-hours expended over 12 months.

Dollars - A program to develop a modularized oil pump would cost approximately $90,000.

Success Probability - High.

Estimated Improvement Potential

The nonrecurring investment required to develop a modularized oil pump appears to be reasonable considering the significant advantages which will result. A high probability of success further encourages continued development. Cost effectiveness of the idea, however, is contingent upon holding the unit cost down to a tolerable level.

## CONCLUSIONS

The objective of this study was to analyze subsystem and component installation techniques used in current Army aircraft and to develop improved design concepts and principles related thereto. The study considered both state-of-the-art applications and the development of new engineering concepts in the solution of installation design problems.

Use of the word "problem" in reference to the subject area of this study is not meant to imply a failing on the part of past designers. To put the situation in proper perspective, it is important to understand the complex set of constraints under which the present helicopter fleet was designed. With each new model, there were intensified demands for greater payload and performance, better reliability, and lower operating costs. Added to the inherent complexity of a vertical lift craft, these demands sorely taxed the ingenuity and innovative skill of the designer. It is not surprising that maintainability, low on a long list of priorities, sometimes suffered in the process.

That maintenance of helicopters is difficult, time-consuming and expensive is known to everyone associated with the field. Selecting areas of study for this program presented little difficulty from the standpoint of identifying many characteristics of design contribution to the problems of helicopter maintenance. Observing that some hardware installations are inaccessible, crowded or complex, for example, requires no special expertise. Understanding the limitations and constraints under which these designs evolved presented the greater difficulty. It should be recognized that another ordering of priorities at the time of design could have produced different results. Had there been a willingness to accept less in performance, for example, a contribution to better maintainability might have been made.

While the thrust of this study was to develop concepts for the design of future helicopters, it is the maintenance problems of today upon which the work focused. In this undertaking, the Army asked that the design of current aircraft be viewed from a totally new perspective, one that places maintainability first on the list of priorities. This changed traditional ground rules significantly and provided freedom for innovative approaches to maintainability that past designers did not enjoy.

The design concept recommendations of both the state-of-the-art and new technology classification were contributed by many

different people in the various engineering groups at Kaman. They represent some possible approaches to problems this study has examined. They are not the only solutions nor, perhaps, the ideal solutions in every case. Another group of engineers confronted with the same set of problems would, assuredly, have arrived at a different mix of responses.

The major effort of this study is embodied in the twelve design study projects. Among these concepts, selected from the most promising of the Phase I design recommendations, there exists a considerable range of complexity and design innovation. The amount of design definition which could be developed in the available time varies accordingly. It is important to stress that, despite the appearance of some design detail, all twelve study projects are purely conceptual, although some are perhaps closer to realization than others.

The analysis of benefits and penalties accompanying the twelve design projects represents the best judgement of the several engineering specialists in whose areas of interest a given concept had some apparent impact. Because the designs are conceptual, the commentary in such areas as stress, weights and aerodynamics is, necessarily, of a qualitative nature. For each of the concepts, one or more potential disadvantages in such areas as cost or performance are identified. Some of these are significant. This was not unexpected, however, since, from the outset, it was known that any major improvements in helicopter maintainability would invite such penalties. More work will be needed to resolve the remaining design problems and to decide whether enough merit exists to pursue some of these concepts to fruition.

The value of this study, apart from the direct benefit it may have for the design of future aircraft, has been that of showing the effect of considering maintainability as the focal point of design. The change in perspective this brought to many people involved with the program was interesting to observe. Design specialists, approached with various types of problems on current-day helicopters, at first had considerable difficulty thinking in terms of alternatives which placed maintainability <u>first</u> among the design objectives. Having been accustomed to considering maintainability with lesser import than performance, weight or cost, it was difficult to contemplate design concepts which accepted penalties in these areas for the sake of better maintenance. As the program progressed, however, these same designers began thinking very constructively and innovatively about maintainability, putting aside, at least temporarily, the more traditional approaches to design. This is not to say that maintainability was absent entirely in earlier design thinking, but it was one of the factors which was accommodated, usually, after the more

important objectives had been met. The emphasis given to maintainability in this study is, by virtue of the fact that it has been oriented entirely toward this one aspect of design, much greater than would be justified in a program involving the total design of an aircraft, of course. But it appears from this work that more positive attitudes toward maintainability should be developed in the future. Like most characteristics of design, maintainability is not so much a matter of sweeping "technological breakthroughs" as it is a thoughtful and well organized approach to the problem.

## RECOMMENDATIONS

In the course of this study, many concepts having a potentially beneficial effect on the maintainability design of future helicopters have been advanced. Twelve of these have been explored in some depth. Some of the concepts, the flange-mounted engine as an example, will probably come into being through normal evolutions in the state of the art. (Flange-mounted engine designs are already being studied by the industry.) In order for some of the other concepts to find a place in the design of future aircraft, however, it will be necessary to undertake developmental activity for that express purpose.

It is recommended that the Government pursue further those design concepts which the work accomplished under this program has shown, in its assessment, to offer significant improvement potential. This activity might take several directions depending upon the anticipated development effort. For concepts involving low to moderate complexity, a prototype design and test program might be considered as the next step. Those of a more ambitious nature would probably warrant additional study work to further explore their feasibility.

END